INSTITUTE OF
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MEASUREMENT OF THE OPTICAL PROPERTIES OF FLOWING SLURRIES OF PULP AND OTHER MATERIALS

Project 3314

Report One
A Progress Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

February 29, 1980

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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BACKGROUND

The problem of measuring the optical properties of wet pulp handsheets and pulp slurries has intrigued technical people in the paper industry for many years. Many different techniques have been tried, and some instruments have been designed specifically for this purpose with varying degrees of success. However, because of the nature of the optical properties of wet pulp, it is extremely difficult to obtain a reflectance measurement which correlates closely with the reflectance of the dry pulp. It is desirable to measure a reflectance which is characteristic of the wet pulp and not influenced by such variables as entrapped air, consistency, mass of pulp, and certain instrumental characteristics. A true measure of R_∞ (see Appendix I for definition of symbols) for the wet pulp would be most desirable; however, because of the high translucency of the wet pulp and certain geometric limitations of the instrument, it is virtually impossible to measure R_∞ directly.

WET HANDSHEETS

In early work, measurements of R_o and R_R' were made on wet handsheets, and the R_∞ value was calculated (1). A technique was developed wherein the wet pulp handsheet was sandwiched between two sheets of thin plastic film (Saran wrap). The composite was then presented to the sample port on the G.E. Recording Spectrophotometer, and reflectances with a black and white backing were obtained. The R_∞ value plus the scattering and absorption coefficients were calculated from the two reflectances (2, 3, 4). In this way, effects of variables such as entrapped air, consistency, mass of fiber, and instrumental factors are minimal, and the "true" optical data can be determined. Data for different types of pulp are given in Tables I and II. Table III gives the data for white oak kraft handsheets with varying amounts of TiO_2. The relationship between the R_∞ values for the wet and dry handsheets is shown in Fig. 1.

TABLE I

REFLECTANCE DATA FOR THREE COMMERCIAL PULPS

	R_o Wet	R_R' Wet	R_∞ Wet	R_∞ Dry
Mixed Hardwood Kraft	0.5042	0.7606	0.7286	0.9054
Softwood Kraft, Fir, Hemlock and Wester Cedar	0.5105	0.7439	0.7038	0.8976
Softwood Kraft, Southern Pine	0.4594	0.7346	0.6772	0.8696

Note: Data are averages of twenty determinations.

The data show that there is a good correlation between the R_∞ values in the dry state for the various types of fibers with differences being of the order of several percent. These differences are probably related to the differences in scattering power in the wet and dry states for the different species. Limiting the data to a single species improves the correlation.

The addition of TiO_2 to the handsheets causes a substantial increase in the scattering coefficient in both the wet and dry states. Figure 2 shows the relationship between the scattering coefficient and R_∞ and the TiO_2 concentration for the wet state. The basis weight determination was made after the handsheets were dried in a conditioned atmosphere at 50% RH and 73°F. The percentage of TiO_2 is based on the air-dried weight of the sheet. The curve indicates that this might be a good means for determining the optical effectiveness of the TiO_2 in the wet state, which relates well to the optical effectiveness in the dry state.

TABLE II

REFLECTANCES, SCATTERING AND ABSORPTION COEFFICIENTS, AND BASIS WEIGHTS FOR WET AND DRY HANDSHEETS

R_o Wet	R_R' Wet	R_∞ Wet	R_∞ Dry	Basis Weight, g/cm^2	k cm^2/g Wet	s cm^2/g Wet	k cm^2/g Dry	s cm^2/g Dry
White Oak Kraft Handsheets								
0.1062	0.1544	0.1127	0.3105	0.00656	174.7	50.1	280.5	366.3
0.2025	0.3143	0.2315	0.4986	0.00908	69.8	54.8	105.3	417.5
0.3440	0.5062	0.4171	0.6874	0.01424	22.9	56.3	31.8	447.0
0.3934	0.5702	0.4865	0.7419	0.01570	15.8	58.5	20.4	453.7
0.4785	0.7140	0.6569	0.8798	0.01796	5.3	59.7	3.8	462.6
Western Hemlock Kraft Handsheets								
0.0983	0.1951	0.1111	0.2497	0.00450	192.1	54.1	237.3	201.0
0.1673	0.2969	0.1962	0.4229	0.00738	85.7	52.1	133.0	292.0
0.2317	0.3708	0.2738	0.5260	0.00972	53.1	55.1	83.6	326.1
0.3232	0.5449	0.4268	0.6936	0.01208	21.0	54.7	29.5	342.2
0.3782	0.6129	0.5101	0.7837	0.01526	12.0	51.4	13.5	374.4
Jack Pine Kraft Handsheets								
0.0885	0.1317	0.0934	0.2923	0.00692	179.1	40.7	292.6	341.5
0.2478	0.5702	0.3900	0.6783	0.00806	24.9	52.0	34.5	452.4
0.3772	0.6152	0.5118	0.7946	0.01626	11.1	47.8	12.3	464.9
0.3924	0.6882	0.5925	0.8507	0.01460	7.2	51.4	5.8	444.0
0.4332	0.7002	0.6249	0.8899	0.01924	5.2	46.7	3.0	441.7

Note: Data are averages of twenty determinations.

TABLE III

WHITE OAK KRAFT HANDSHEETS WITH TiO_2 ADDED

R_o Wet	R_R' Wet	R_∞ Wet	R_∞ Dry	Basis Weight, g/cm^2	k cm^2/g Wet	s cm^2/g Wet	k cm^2/g Dry	s cm^2/g Dry	TiO_2 %
0.5099	0.7503	0.7139	0.9017	0.0174	3.78	66.9	2.42	464.0	0.00
0.6550	0.7910	0.7916	0.9096	0.01767	3.30	121.9	2.38	531.3	0.72
0.7794	0.8301	0.8358	0.9153	0.01667	4.36	280.1	2.55	649.9	2.67
0.8404	0.8671	0.8785	0.9219	0.01937	3.02	359.6	2.66	801.2	5.58

Note: Data are averages of twelve determinations.

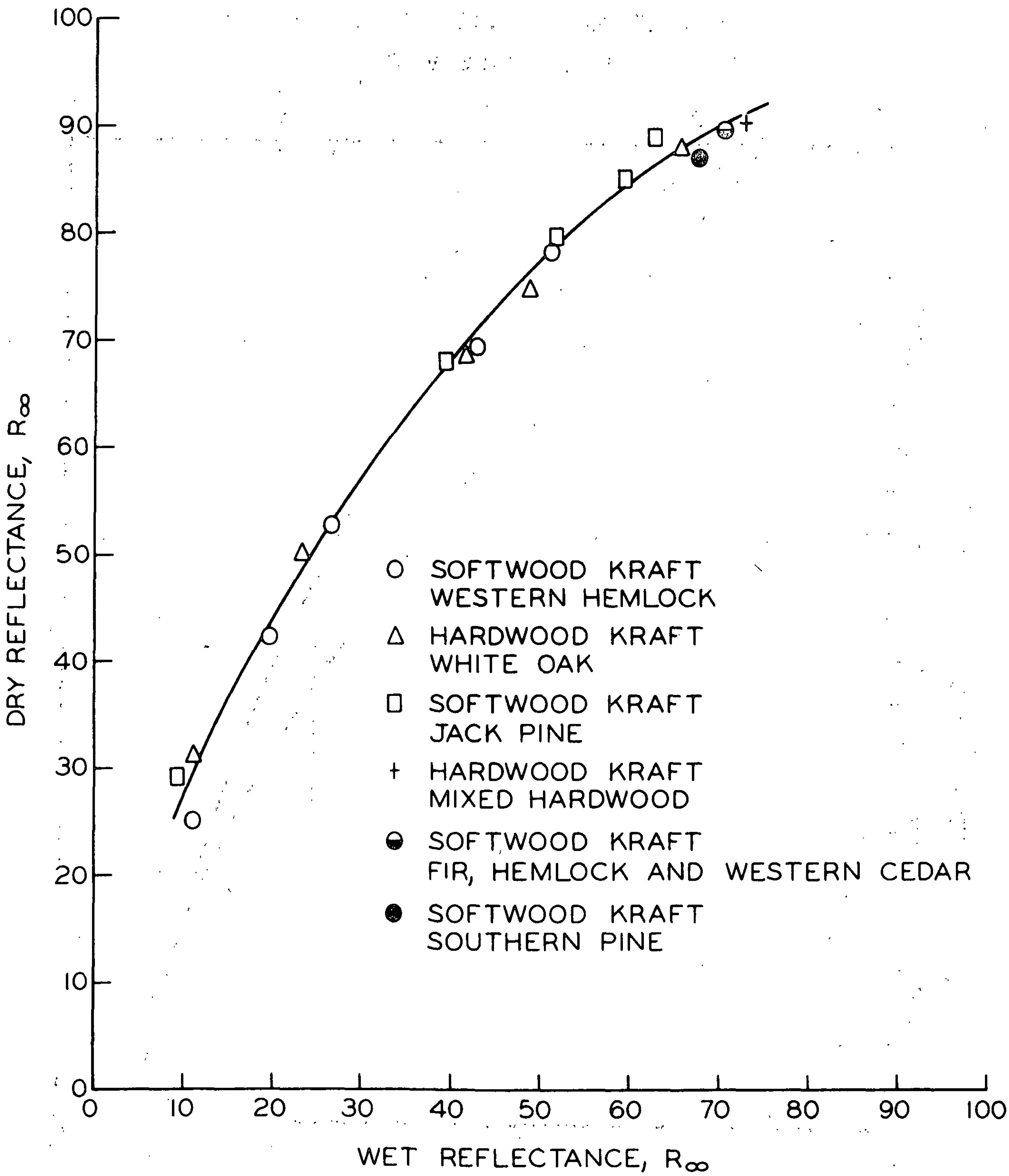

Figure 1. Relationship Between Reflectance in the Dry State and Reflectance in the Wet State for Six Types of Pulp

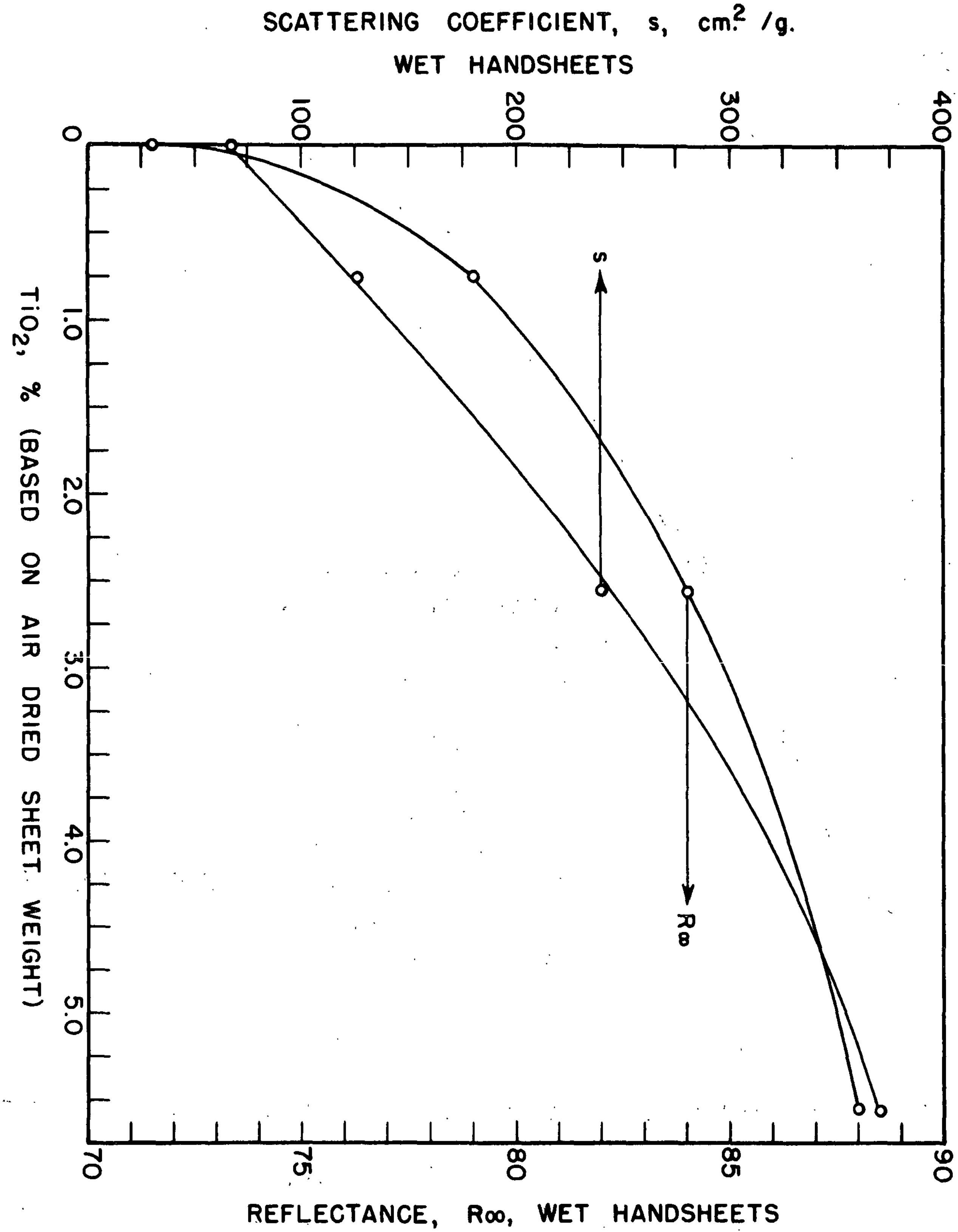

Figure 2. Influence on Scattering Coefficient and Reflectance Upon Addition of TiO_2 to the Wet Handsheets

MEASUREMENTS ON PULP SLURRIES

The good correlation between the data for the wet and dry handsheets was encouraging, so the design of an instrument for possible use in the paper mill was begun. While the G.E. Recording Spectrophotometer is an excellent instrument for measuring reflectance, and the handsheets are ideal with respect to thickness, neither could be used in the mill operation. The instrument for measurements on pulp slurries must be designed to mount in the pulp transport system, and the slurry passageway must have appropriate dimensions so that high-consistency stock can be pumped through it. An instrument was designed and constructed to measure transmittance and reflectance, rather than two reflectances. This eliminates the need for changing the backing reflectance.

The double integrating cavity instrument, called the Wet Optical Properties Tester (WOPT), was constructed with the upper cavity collecting the reflected radiation and the lower cavity collecting the transmitted radiation. A schematic diagram and photograph of the instrument are shown in Fig. 3 and 4 respectively.

The instrument illuminates the slurry with a beam of light of about 1.6 cm (5/8 inch) diameter, and the specimen aperture is about 5.7 cm (2.25 inch) diameter. The loss of radiation at the aperture is minimized by illuminating a small spot and viewing a large area. Through use of two prisms with shutter arrangements, the calibration of the instrument can be checked while the pulp slurry is flowing through the instrument. In one case, the light beam is directed to the upper cavity lining and, in the other case, it is directed to the lower cavity lining for calibration purposes. The instrument was equipped with appropriate filters to match the spectral function for the measurement of papermaker's brightness.

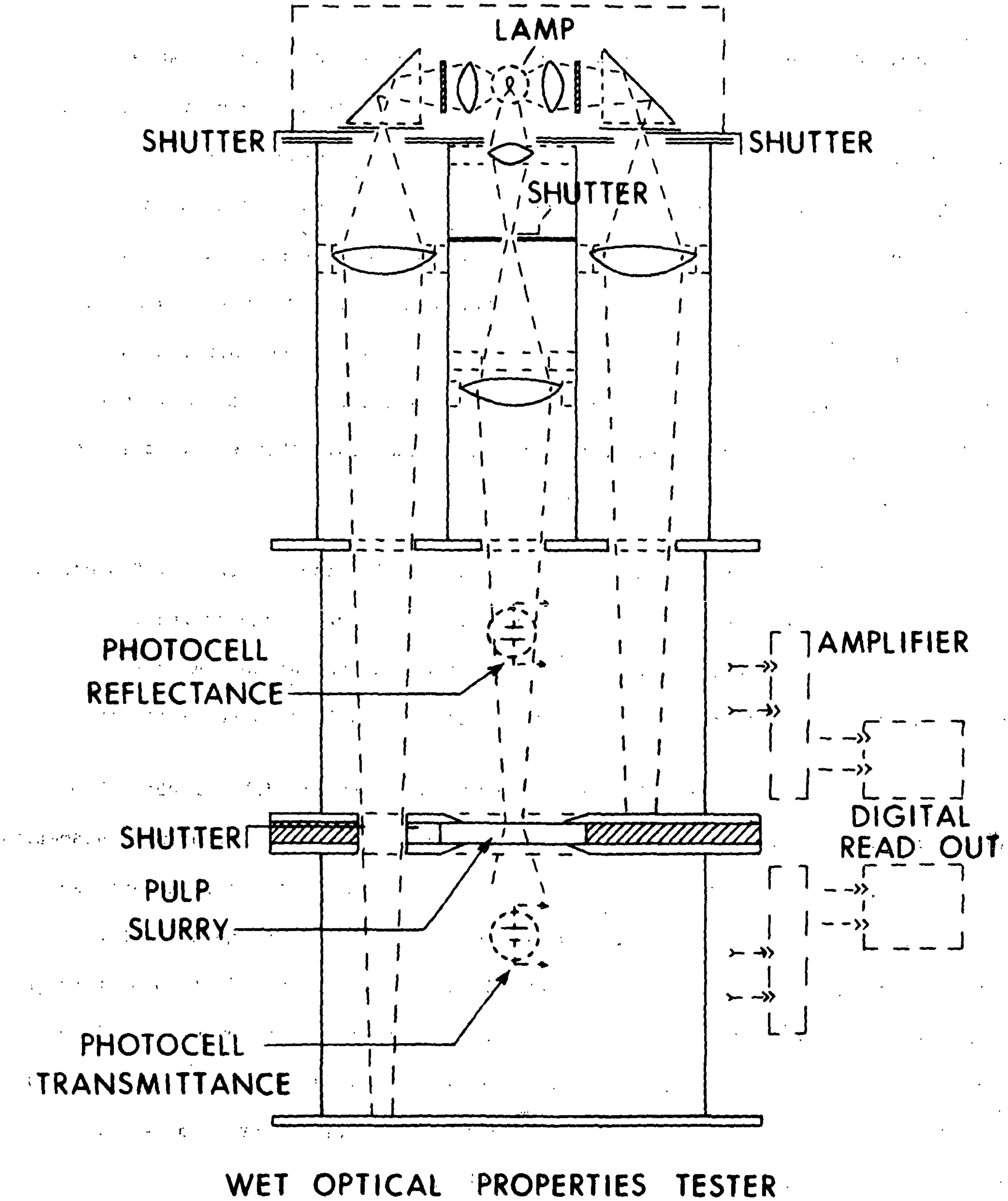

Figure 3. Schematic Diagram of the Wet Optical Properties Tester

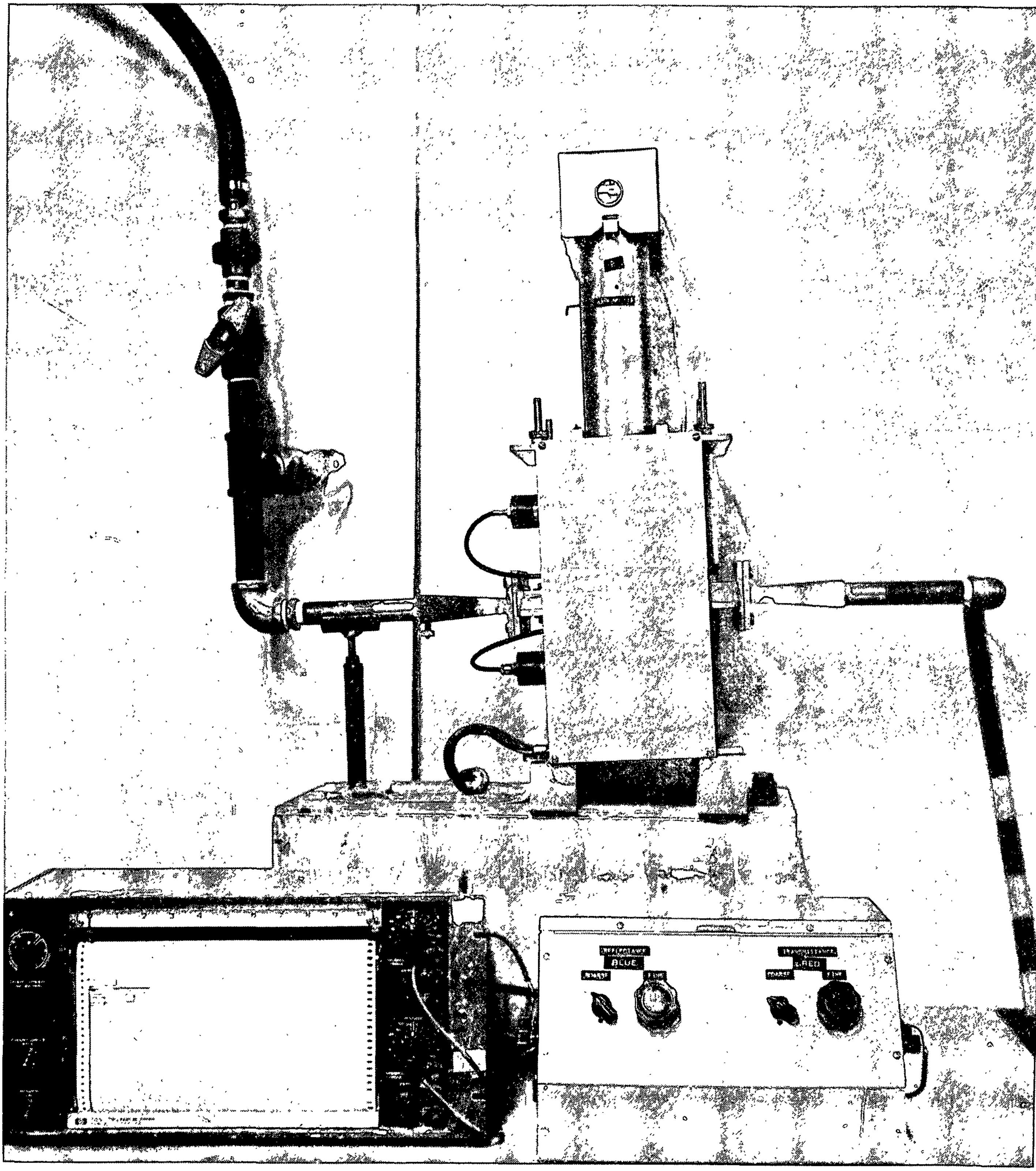

Figure 4. The Wet Optical Properties Tester

The slurry passageway was 1.27 x 10.16 cm (0.5 x 4 - inches) with appropriate inlet and outlet fittings to change from a circular pipe to the rectangular passageway.

Using the instrument, we obtained data for a number of pulp samples. Four readings were taken for each evaluation. The reflectance reading plus the reflectance calibration check point and the transmittance reading plus the transmittance calibration check point were recorded. After adjusting for the calibration check point, we determined the scattering power and the absorption power through use of approximation formulas.

The approximation formulas for scattering power (sW) and absorbing power (kW) are R_o/T and $(1-R_o-T) + (1-R_o-T)^2$ respectively. Scattering power is related to consistency by multiplying the ratio R_o/T by the empirical factor 1.3. The sum of R_o and T was related to brightness directly in the wet state. Brightness in the dry state was calculated from $(R_o + T)$ using the following relationship:

$$k/s = \frac{(1-R_o -T)^2}{2\ (R_o +T)}$$

$$A = 0.11\ k/s$$

$$R_\infty\ (\text{dry}) = 1+A- \sqrt{(A)^2+ (2A)}$$

The empirical factor 0.11 was chosen to give the best agreement between the brightness values calculated from the wet state and those actually measured in the dry state.

The data for several pulps at several brightness levels are given in Table IV. There is good agreement between the consistencies calculated from WOPT data and the gravimetrically determined consistencies. Also, the agreement

TABLE IV

REFLECTANCE AND TRANSMITTANCE DATA COLLECTED WITH THE WET OPTICAL PROPERTIES TESTER, CONSISTENCY AS DETERMINED GRAVIMETRICALLY AND STANDARD BRIGHTNESS

Sample	R_o	T	R_o + T	R_o/T	Consistency, % 1.3(R_o/T)	Gravimetric	Calculated Brightness	Standard Brightness
Nov. 3, 76	0.4162	0.2580	0.6742	1.6132	2.10	2.18	0.877	0.877
Bleached	0.3561	0.3071	0.6632	1.1596	1.51	1.52	0.872	
Spruce	0.2843	0.3479	0.6322	0.8172	1.06	0.99	0.858	
Kraft	0.1870	0.4401	0.6271	0.4249	0.55	0.48	0.856	
Nov. 23, 76	0.0249	0.0048	0.0297	5.1875	6.74	1.93	0.189	0.209
Unbleached	0.244	0.0058	0.0302	4.2069	5.47	1.80	0.191	
Kraft	0.0238	0.0144	0.0382	1.6528	2.15	1.27	0.225	
Softwood	0.0223	0.426	0.0649	0.5235	0.68	1.03	0.316	
Jan. 19, 77	0.4017	0.2575	0.6592	1.5600	2.03	2.07	0.870	0.876
Bleached	0.3528	0.3001	0.6529	1.1756	1.53	1.58	0.867	
Spruce	0.2853	0.3463	0.6316	0.8239	1.07	1.08	0.858	
Kraft	0.1879	0.4301	0.6180	0.4369	0.57	0.54	0.851	
Jan. 19, 77	0.2783	0.2144	0.4927	1.2980	1.69	1.75	0.787	0.808
Pulp No. 1	0.2646	0.2398	0.5044	1.1034	1.43	1.49	0.794	
Hardwood	0.2408	0.2864	0.5274	0.8408	1.09	1.16	0.806	
4th Washer	0.1838	0.3884	0.5722	0.4732	0.62	0.61	0.829	
Jan. 19, 77	0.2791	0.2474	0.5265	1.1281	1.47	1.66	0.806	0.802
Pulp No. 2	0.2528	0.3274	0.5802	0.7721	1.00	1.07	0.833	
Hardwood	0.1965	0.4302	0.6267	0.4568	0.59	0.55	0.855	
4th Washer								
Jan. 19, 77	0.3120	0.1820	0.4940	1.7143	2.23	2.15	0.788	0.799
Pulp No. 3	0.2947	0.2247	0.5194	1.3115	1.70	1.64	0.802	
Hardwood	0.2542	0.2978	0.5520	0.8536	1.11	1.12	0.819	
4th Washer	0.1916	0.3827	0.5743	0.5007	0.65	0.64	0.830	
Jan. 19, 77	0.3786	0.2806	0.6592	1.3493	1.75	1.93	0.870	0.880
Pulp No. 4	0.3362	0.3174	0.6536	1.0592	1.38	1.44	0.868	
Hardwood	0.2783	0.3597	0.6380	0.7737	1.01	1.00	0.861	
4th Washer	0.1950	0.4380	0.6330	0.4452	0.58	0.43	0.858	
Feb. 1, 77	0.3167	0.2682	0.5849	1.1808	1.54	1.76	0.835	0.812
Pulp No. 1	0.2835	0.3130	0.5965	0.9058	1.18	1.37	0.841	
Softwood	0.2563	0.3363	0.5926	0.7621	0.99	1.14	0.839	
4th Washer	0.2012	0.4039	0.6051	0.4981	0.65	0.73	0.845	
Feb. 1, 77	0.2228	0.2063	0.4291	1.0800	1.40	1.63	0.750	0.731
Pulp No. 2	0.2004	0.2592	0.4596	0.7731	1.01	1.21	0.768	
Softwood	0.1893	0.3024	0.4917	0.6260	0.81	0.90	0.787	
4th Washer	0.1667	0.3707	0.5374	0.4497	0.58	0.72	0.811	
Feb. 1, 77	0.2261	0.1910	0.4171	1.1838	1.54	1.68	0.742	0.720
Pulp No. 3	0.2033	0.2587	0.4620	0.7859	1.02	1.14	0.770	
Softwood	0.1890	0.2999	0.4889	0.6302	0.82	0.99	0.785	
4th Washer	0.1550	0.3965	0.5515	0.3909	0.51	0.62	0.819	
Feb. 1, 77	0.1927	0.2009	0.3936	0.9592	1.25	1.39	0.727	0.691
Pulp No. 4	0.1857	0.2190	0.4047	0.8479	1.10	1.27	0.734	
Softwood	0.1799	0.2586	0.4385	0.6957	0.90	1.08	0.745	
4th Washer	0.1583	0.3428	0.5011	0.4618	0.69	0.72	0.792	
Feb. 15, 77	0.3936	0.2487	0.6423	1.5826	2.06	1.97	0.863	0.847
Pulp No. 1-400	0.3392	0.2963	0.6355	1.1448	1.49	1.37	0.859	
Softwood	0.2937	0.3306	0.6243	0.8884	1.15	1.01	0.854	
Refined	0.2098	0.3949	0.6047	0.5313	0.69	0.60	0.845	
Feb. 15, 77	0.3996	0.2398	0.6394	1.6663	2.17	2.04	0.861	0.845
Pulp No. 2-350	0.3614	0.2811	0.6425	1.2857	1.67	1.53	0.863	
Softwood	0.3438	0.2961	0.6399	1.1611	1.51	1.34	0.862	
Refined	0.2547	0.3605	0.6152	0.7065	0.92	0.79	0.850	
Feb. 15, 77	0.4047	0.2278	0.6325	1.7766	2.31	2.37	0.857	0.841
Pulp No. 3-300	0.3626	0.2802	0.6428	1.2941	1.68	1.67	0.863	
Softwood	0.3042	0.3314	0.6356	0.9179	1.19	1.17	0.859	
Refined	0.2390	0.3831	0.6221	0.6239	0.81	0.73	0.853	

between brightness calculated from WOPT data and brightness determined in accordance with TAPPI standard method T-452 is good, particularly at the higher consistencies.

This Wet Optical Properties Tester was placed in a mill for a trial run. It was found that, when colored water was present, the data were not meaningful. When WOPT was moved to a location where the stock was washed, the data were more meaningful. The device ultimately failed because of a design weakness. It was not designed to withstand the mill environment.

A second instrument was constructed with several improvements. This instrument, called WOPT II and shown schematically in Fig. 5, was designed to measure reflectance and transmittance using the double cavity but with changes in the arrangement for calibration. A calibration "paddle" was located in the upper cavity which could be rotated into or out of the beam. This paddle was coated with the barium sulfate-Halon paint having an absolute reflectance of about 0.96. A fiber optics tube was used to transmit light from the lamp to the lower cavity for calibration of transmittance. A rotating shutter around the lamp permits directing the light to the sample port or to the fiber optics tube as desired. A piece of 5.08 cm (2 inch) inside diameter flexible tubing was placed between the cavities to transport the pulp slurry. A photograph of the device is shown in Fig. 6.

Preliminary measurements performed with WOPT II were made on a very stable fluid having a high reflectance in the fluid state. The fluid, rubber latex GENFLO 599,* has an absolute reflectance in the fluid state of about 0.980. This "ideal" fluid permits calibration of the instrument as the "consistency" and "brightness" can be adjusted to give scattering and absorption

*General Tire Co., Akron, OH.

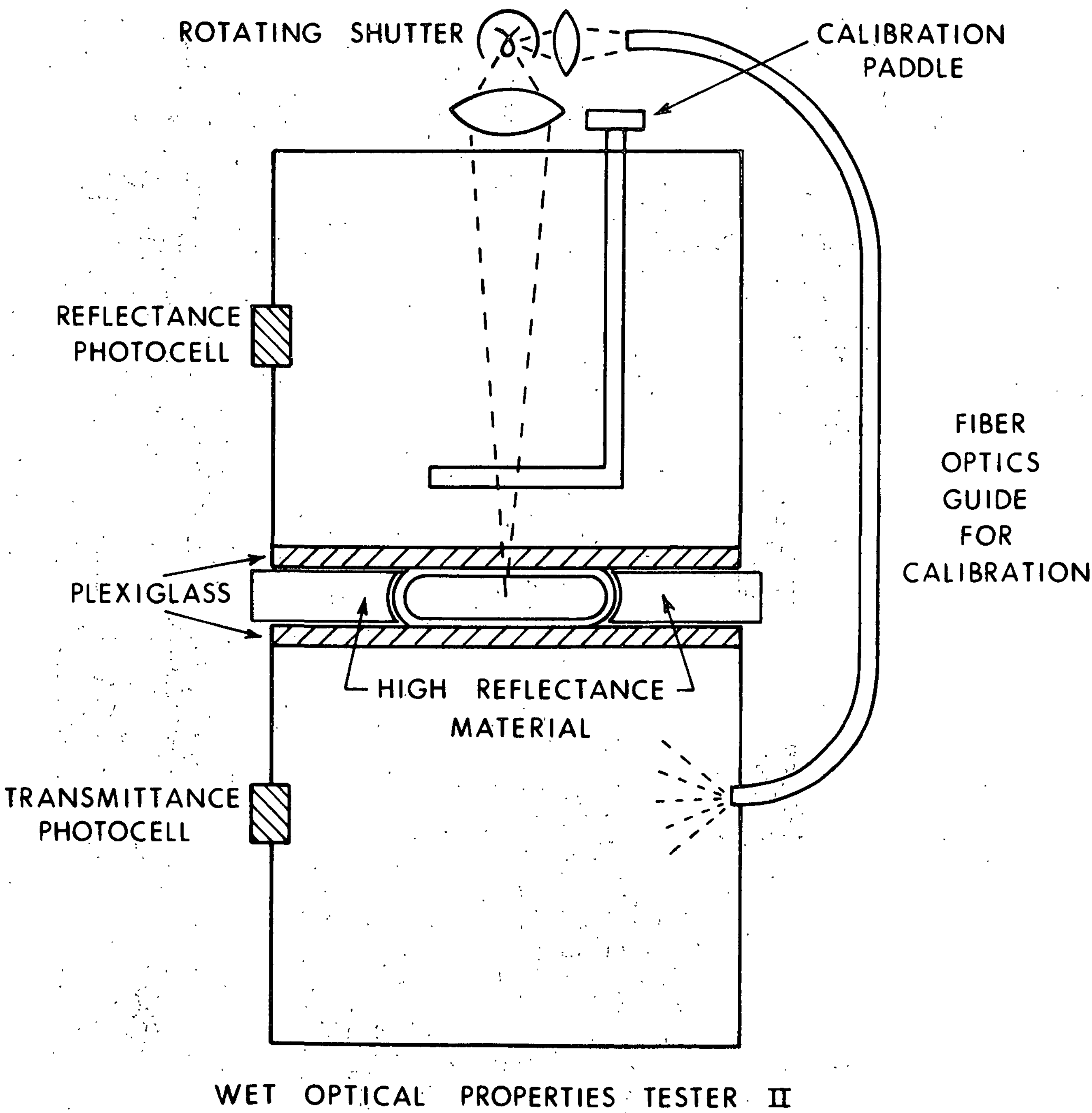

Figure 5. Schematic of the Second Wet Optical Properties Tester

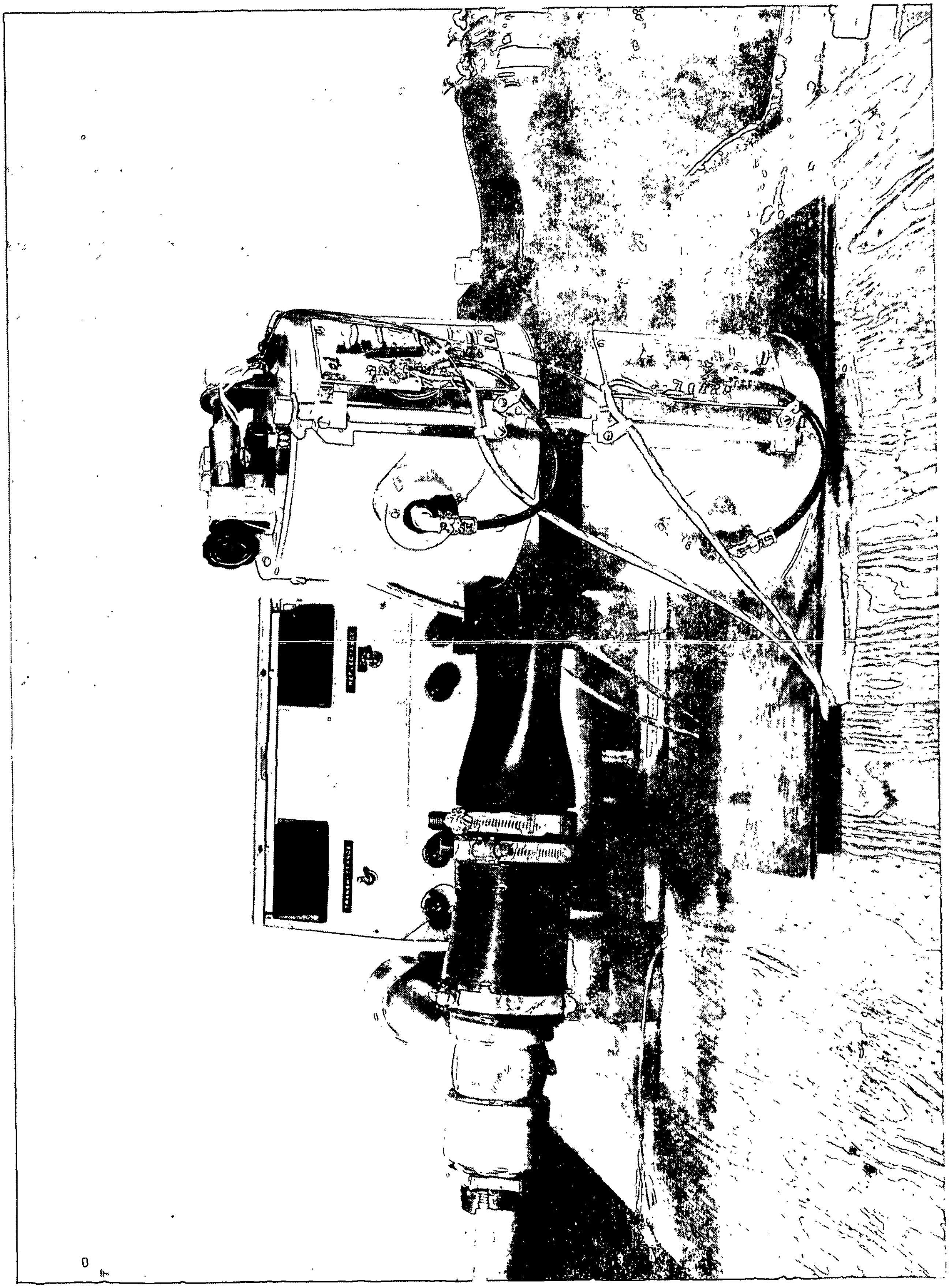

Figure 6. The Second Wet Optical Properties Tester

characteristics similar to most pulps. The "consistency" was varied by dilution with water and the "brightness" was varied by adding a black dye. The "consistency" was known accurately through addition of known amounts of water. The "brightness" with various levels of black dye could be measured directly with the G.E. Recording Spectrophotometer. A minimum period of about two days was required before the fluid with the black dye would reach an equilibrium reflectance as measured by the G.E. Recording Spectrophotometer. The reflectance of this fluid was checked over a period of one month with no observable change.

Reflectance and transmittance data were obtained for the original rubber latex and after addition of several levels of black dye. The data are given in Table V. The first column gives the concentration of latex. The second and third columns give the reflectance and transmittance values read directly from WOPT II. The double cavity effect, residual single beam error, and edge effects were accounted for in such a manner as to give close agreement between the calculated values for WOPT II and the G.E. Recording Spectrophotometer at the highest concentration of latex particles with various additions of black dye.

Columns four and five give the corrected R_o and T values. Columns six and seven give the scattering and absorbing power as calculated in accordance with the Kubelka-Munk relationship. Column eight gives the R_∞ value calculated from the corrected R_o and T values. Column nine gives the R_∞ values determined with the G.E. Recording Spectrophotometer for the highest concentration of latex particles. It was assumed that dilution would not change the R_∞ value. There is very close agreement between the calculated R_∞ values from WOPT II data and the R_∞ value determined with the G.E. Recording Spectrophotometer for the range of scattering power from 0.37 to 51.94 and absorbing power from 0.0007 to 2.241. This range is about the equivalent of dry pulp brightness from about 60 to 99%.

TABLE V

OPTICAL DATA FOR RUBBER LATEX GENFLO 559 (WOPT II)

Latex, %	R	T	R_o	T	sW	kW	WOPT II R_∞	GERS R_∞
4.0	0.973	0.038	0.969	0.013	51.94	0.0203	0.972	0.972
1.5	0.954	0.076	0.947	0.045	20.12	0.0084	0.971	0.972
0.5	0.889	0.178	0.868	0.129	6.68	0.0023	0.974	0.972
0.12	0.687	0.475	0.614	0.386	1.59	0.0007	0.972	0.972
1.0	0.770	0.026	0.727	0.008	12.45	0.640	0.727	0.727
0.5	0.767	0.094	0.723	0.065	6.20	0.312	0.729	0.727
0.25	0.729	0.256	0.674	0.200	2.92	0.144	0.732	0.727
0.125	0.652	0.431	0.576	0.351	1.58	0.077	0.733	0.727
0.6	0.574	0.020	0.503	0.008	6.19	1.518	0.503	0.502
0.3	0.570	0.096	0.498	0.072	3.14	0.777	0.502	0.502
0.15	0.551	0.282	0.473	0.230	1.64	0.388	0.509	0.502
0.073	0.484	0.521	0.390	0.438	0.84	0.194	0.513	0.502
0.3	0.300	0.034	0.236	0.025	1.82	2.241	0.236	0.233
0.15	0.298	0.139	0.233	0.116	1.05	1.292	0.237	0.233
0.075	0.285	0.433	0.209	0.373	0.49	0.565	0.245	0.233
0.050	0.265	0.533	0.185	0.462	0.37	0.448	0.238	0.233

A plot of the scattering power as related to latex concentration is shown in Fig. 7-10. There is a linear relationship between scattering power and latex concentration for a wide range of reflectances.

Similar data obtained for several pulps are given in Table VI. The empirical factor 1.6 was established to give the best agreement between the calculated consistency and measured consistency for the bleached jack pine. Brightness of the pulp calculated from WOPT II data for various consistencies are shown in Fig. 11 and 12. The horizontal straight line represents the brightness level as determined in accordance with TAPPI Standard Method T-452.

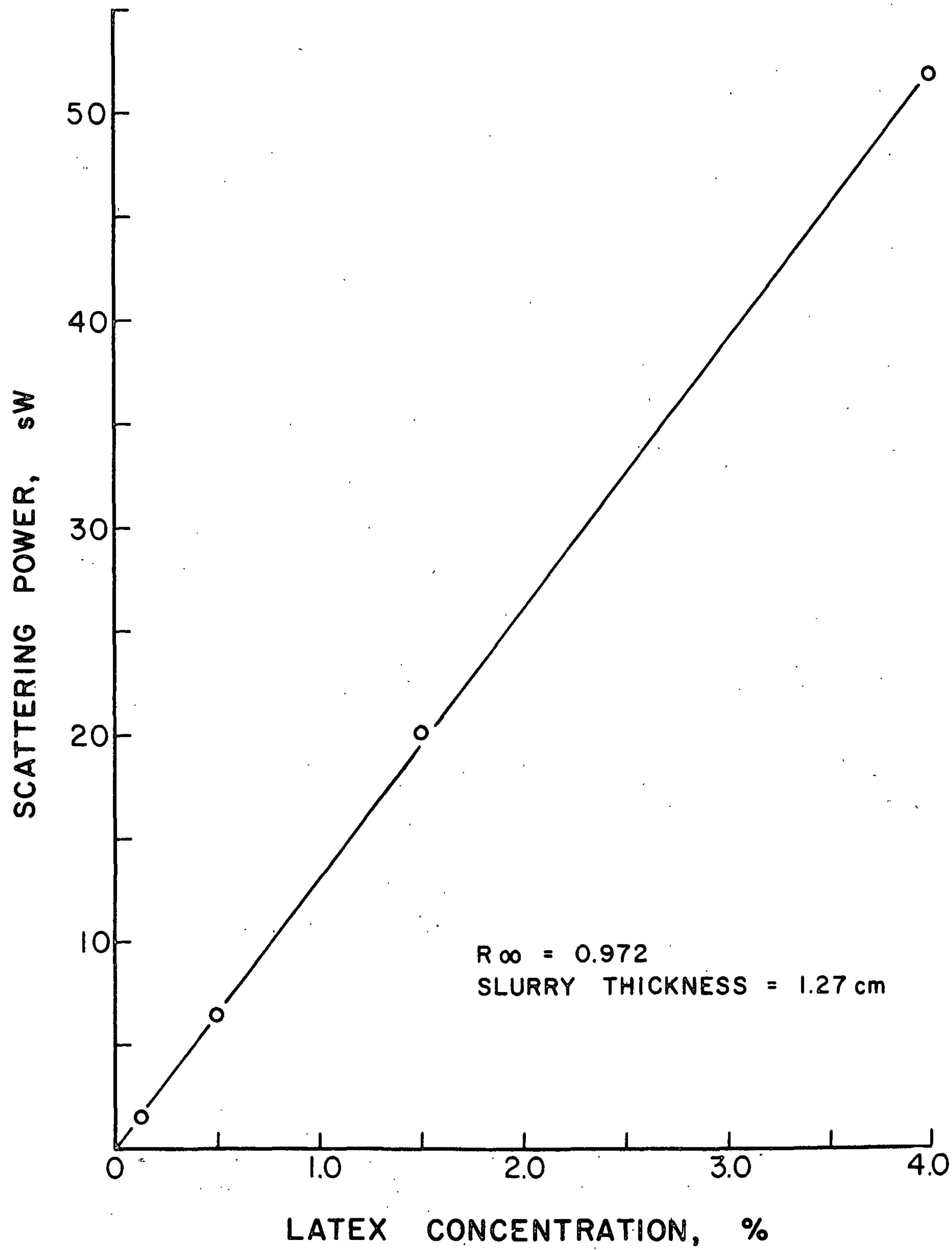

Figure 7. Relationship Between Scattering Power and Concentration of GENFLO 559 Rubber Latex in Water With Flexible Tubing Between the Cavities

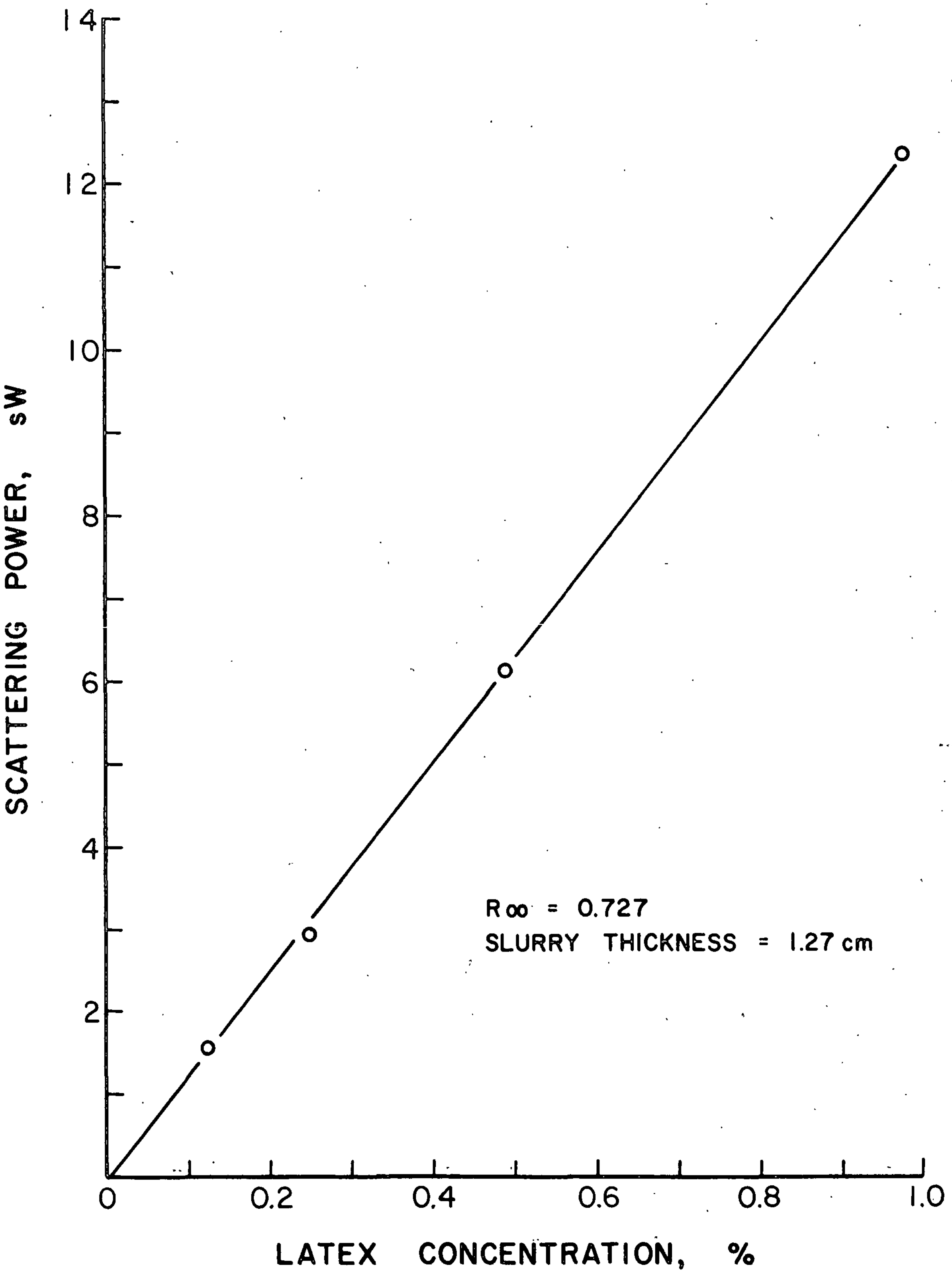

Figure 8. Relationship Between Scattering Power and Concentration of GENFLO 559 Rubber Latex With Black Dye Added and With Flexible Tubing Between the Cavities

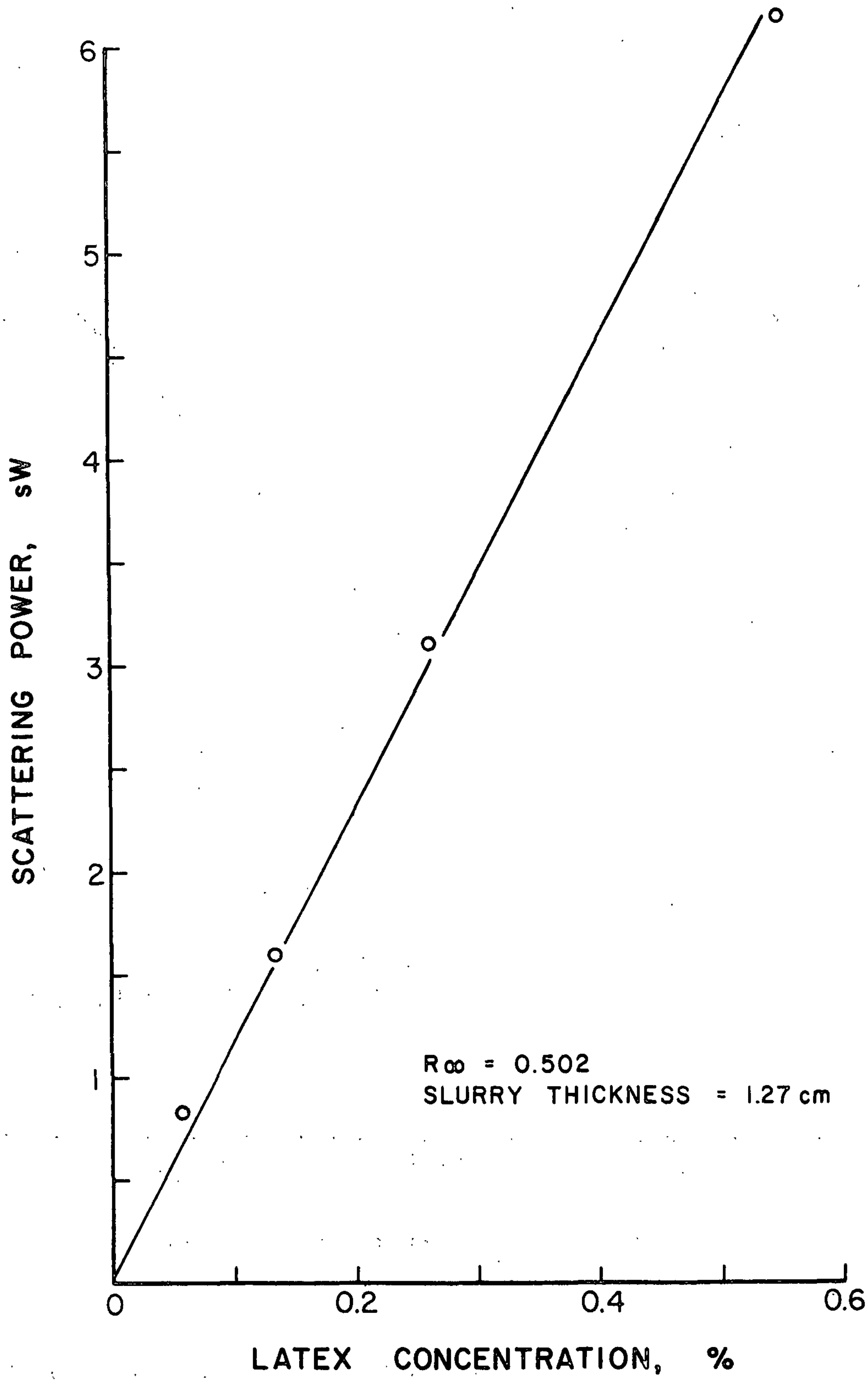

Figure 9. Relationship Between Scattering Power and Concentration of GENFLO 559 Rubber Latex With Black Dye Added and With Flexible Tubing Between the Cavities

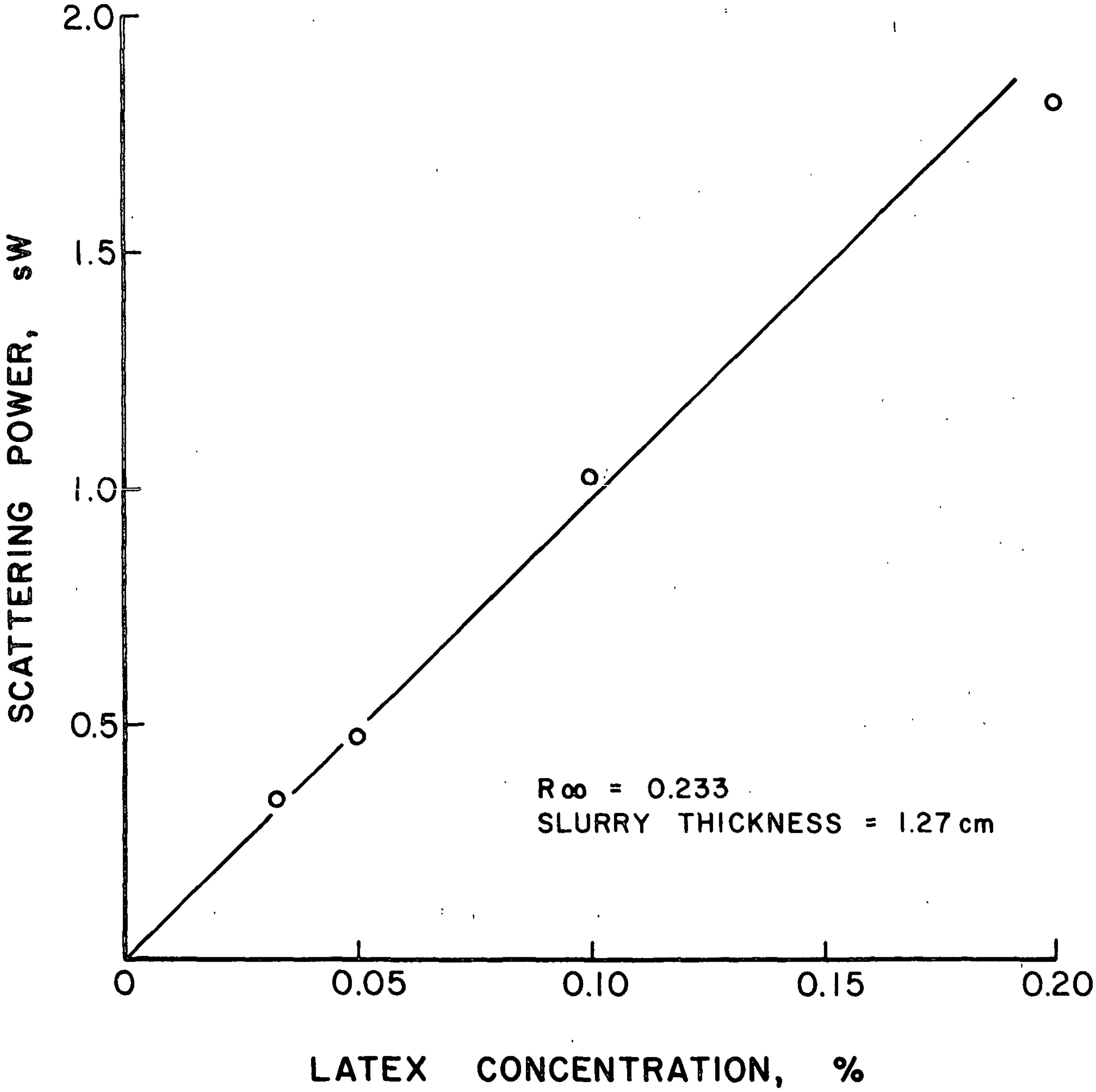

Figure 10. Relationship Between Scattering Power and Concentration of GENFLO 559 Rubber Latex With Black Dye Added and With Flexible Tubing Between the Cavities

TABLE VI

OPTICAL AND CONSISTENCY DATA FOR FIVE PULPS (WOPT II)

R_o	T	sW	kW	R_∞ wet	R_∞ dry	sW x 1.6[a]	Consistency, % gravimetric
Bleached Jack Pine							
0.4640	0.4699	0.9650	0.0691	0.6865	0.8821	1.544	1.55
0.4135	0.5255	0.7736	0.0634	0.6689	0.8744	1.238	1.18
0.3082	0.6552	0.4675	0.0374	0.6719	0.8758	0.748	0.73
0.1934	0.7862	0.2455	0.0207	0.6649	0.8727	0.393	0.39
0.0979	0.8850	0.1105	0.0173	0.5754	0.2308	0.177	0.20
Mixed Hardwood							
0.4581	0.2998	1.3270	0.2951	0.5194	0.8019	2.123	2.05
0.4193	0.3480	1.016	0.2355	0.5130	0.7983	1.626	1.55
0.3413	0.5205	0.6330	0.1511	0.5077	0.7945	1.013	0.89
0.2552	0.6642	0.0380	0.0844	0.5195	0.8020	0.608	0.48
0.1662	0.7993	0.2073	0.0351	0.5630	0.8246	0.332	0.25
Bleached Aspen							
0.5097	0.4089	1.203	0.0864	0.6860	0.8819	1.925	1.98
0.4530	0.4779	0.9263	0.0724	0.6752	0.8772	1.482	1.51
0.3450	0.5991	0.5693	0.0478	0.6395	0.8613	0.9109	0.88
0.2331	0.7318	0.3173	0.0358	0.6244	0.8543	0.508	0.48
0.1381	0.8446	0.1633	0.0175	0.6317	0.8577	0.261	0.25
Mitscherlich Pulp Spruce							
0.4990	0.2565	1.634	0.3033	0.5487	0.8173	2.614	2.01
0.4637	0.3281	1.264	0.2455	0.5415	0.8136	2.024	1.52
0.3947	0.4681	0.8070	0.1505	0.5480	0.8169	1.291	0.88
0.3286	0.5986	0.5409	0.0761	0.5919	0.8389	0.865	0.48
0.2213	0.7654	0.2888	0.0134	0.7380	0.9038	0.462	0.25
Brown Stock Spruce							
0.2065	0.2472	0.6265	0.8625	0.2206	0.5806	1.002	1.36
0.2088	0.3390	0.5191	0.6352	0.2376	0.5986	0.831	0.98
0.2063	0.5156	0.3441	0.3327	0.2876	0.6459	0.603	0.59
0.1956	0.6551	0.2925	0.1630	0.3636	0.7059	0.468	0.40
0.1479	0.8410	0.1858	0.0112	0.7008	0.8883	0.281	0.20

[a]Factor of 1.6 determined to give best agreement between calculated and gravimetically measured consistency for the jack pine furnish.

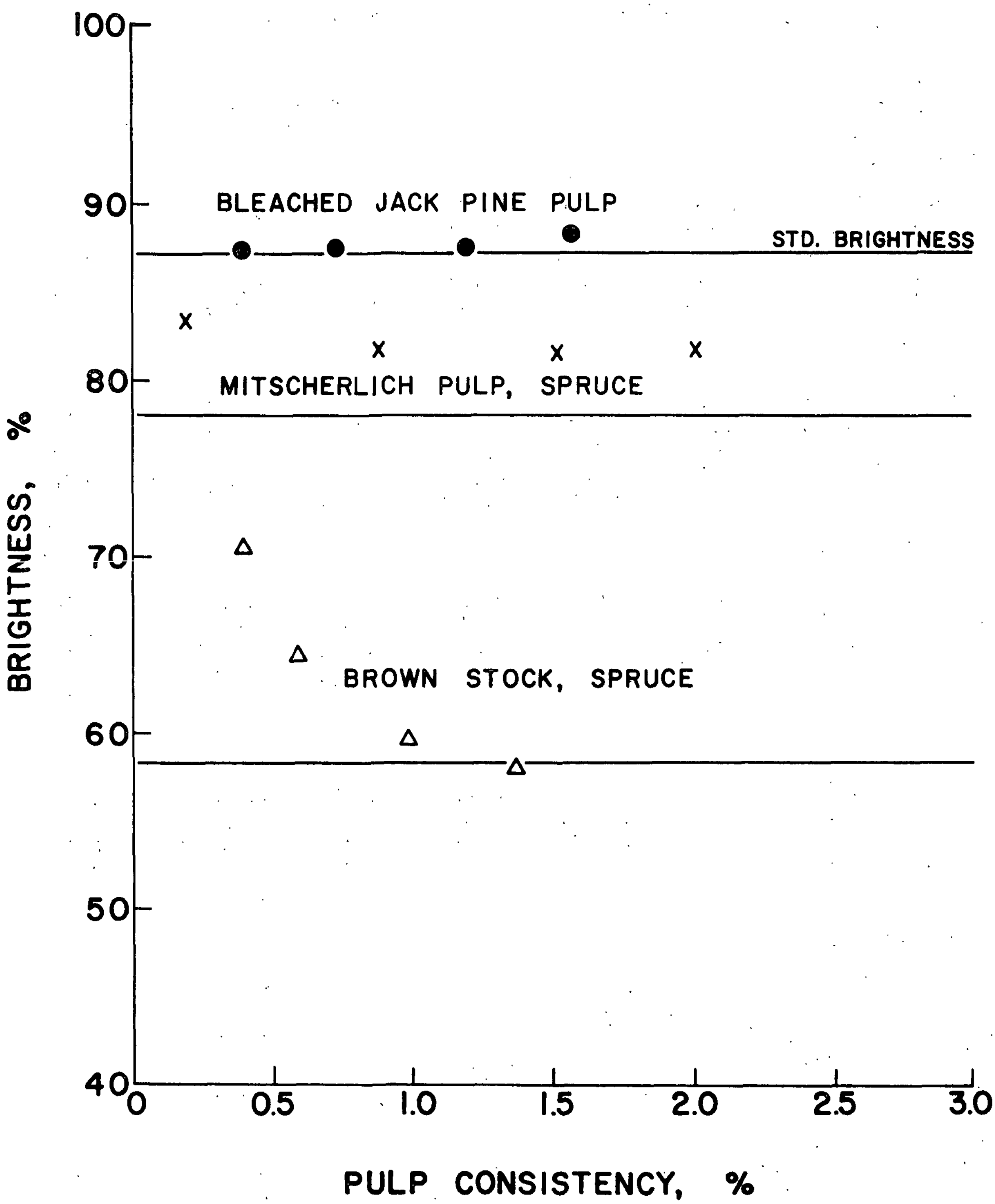

Figure 11. Relationship Between Brightness and Pulp Consistency for Three Different Types of Pulp. Flexible Tubing Between the Cavities

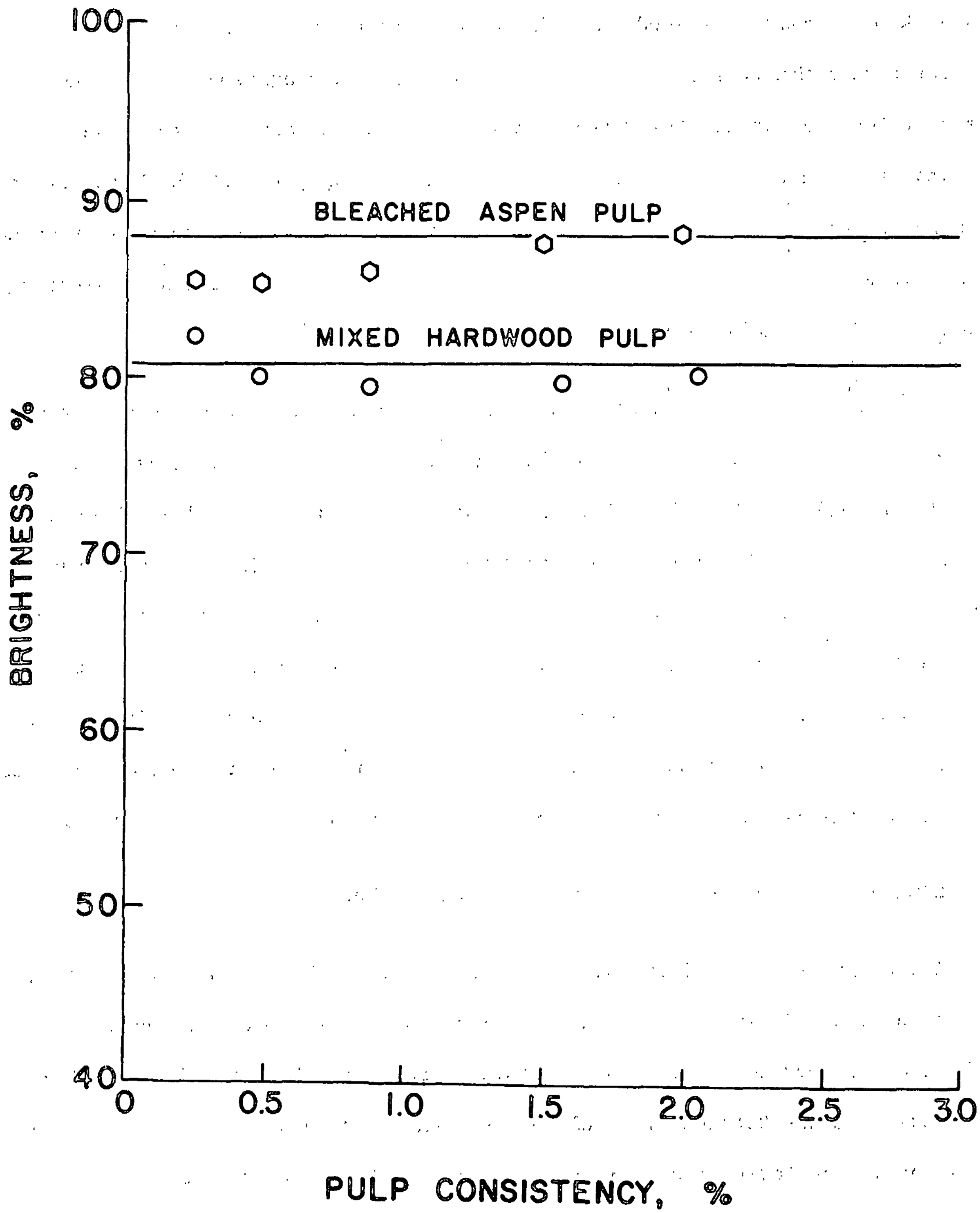

Figure 12. Relationship Between Standard Brightness and Pulp Consistency for Two Different Types of Pulp. Flexible Tubing Between the Cavities

The data show that agreement between the actual brightness values and the values determined from the WOPT II data varies from good agreement for the bleached jack pine, mixed hardwood, and the spruce brown stock to about 3 to 4% high for the spruce Mitscherlich pulp. Also, there is close agreement among the consistency values except for the Mitscherlich pulp. The consistency from the WOPT II data is too high. In the wet state, the scattering power of the Mitscherlich pulp is significantly higher than that of the other pulps. The difference is reduced in the dry state. This would account for both the higher brightness and consistency prediction. It is probably related to the pulping process.

The piece of flexible tubing in WOPT II was replaced with a rigid, transparent, plastic channel having a rectangular shape. The inside dimensions were 1.59 x 14.29 cm (5/8 x 5.62 inch). The illuminated spot size remained at about 1.59 cm (5/8 inch) diameter. The viewing aperture was about 12.7 cm (5 inch) diameter. The rubber latex GENFLO 559 was again evaluated, and the data are given in Table VII. These data also show good agreement between the reflectance values calculated from WOPT II data and the reflectance values obtained with the G.E. Recording Spectrophotometer. Also, a linear relationship exists between the latex concentration and scattering power for a wide range of reflectance values as shown in Fig. 13, 14 and 15.

Similar data for the five pulps are given in Table VIII.

The brightness data from the table are plotted in Fig. 16 and 17. Again, the straight horizontal lines represent the brightness as determined in accordance with TAPPI Standard Method T-452. The consistency data are shown in Fig. 18. These data also show that the Mitscherlich pulp gives higher readings for both brightness and consistency. The formulas used in calculating the final optical data are given in Appendix II.

TABLE VII

OPTICAL DATA FOR GENFLO 559 (WOPT II)

			Corrected				WOPT II	GERS
Latex, %	R	T	R_o	T	sW	kW	R_∞	R_∞
2.08	0.937	0.038	0.9499	0.0384	22.58	0.0124	0.967	0.962
1.56	0.925	0.050	0.9403	0.0507	17.58	0.0093	0.968	0.962
1.06	0.902	0.067	0.9246	0.0687	13.04	0.0074	0.967	0.962
0.53	0.835	0.117	0.8727	0.1232	7.02	0.0042	0.966	0.962
0.26	0.731	0.195	0.7829	0.2146	3.64	0.0025	0.963	0.962
0.11	0.559	0.333	0.6040	0.3947	1.53	0.0013	0.959	0.962
1.42	0.622	0.002	0.7219	0.0023	16.07	0.8606	0.722	0.715
1.16	0.622	0.005	0.7207	0.0058	13.25	0.7167	0.721	0.715
0.91	0.621	0.014	0.7203	0.0163	10.15	0.5498	0.721	0.715
0.66	0.616	0.039	0.7165	0.0453	7.07	0.3865	0.720	0.715
0.48	0.609	0.078	0.7098	0.0912	5.06	0.2705	0.722	0.715
0.35	0.596	0.129	0.6951	0.1499	3.70	0.1874	0.728	0.715
0.26	0.573	0.192	0.6673	0.2172	2.73	0.1299	0.735	0.715
0.18	0.538	0.235	0.6250	0.2810	2.07	0.1022	0.731	0.715
0.11	0.223	0.640	0.1238	0.8687	0.14	0.0075	0.724	0.715
1.05	0.390	0.002	0.5190	0.0025	8.06	1.797	0.519	0.525
0.79	0.388	0.008	0.5187	0.0100	6.09	1.359	0.519	0.525
0.53	0.383	0.035	0.5137	0.0436	3.96	0.905	0.515	0.525
0.26	0.370	0.150	0.4910	0.1879	1.94	0.441	0.515	0.525
0.11	0.318	01346	0.3877	0.4437	0.82	0.190	0.514	0.525
0.05	0.263	0.489	0.2691	0.6425	0.41	0.093	0.517	0.525
0.02	0.217	0.623	0.1399	0.8325	0.17	0.028	0.565	0.525

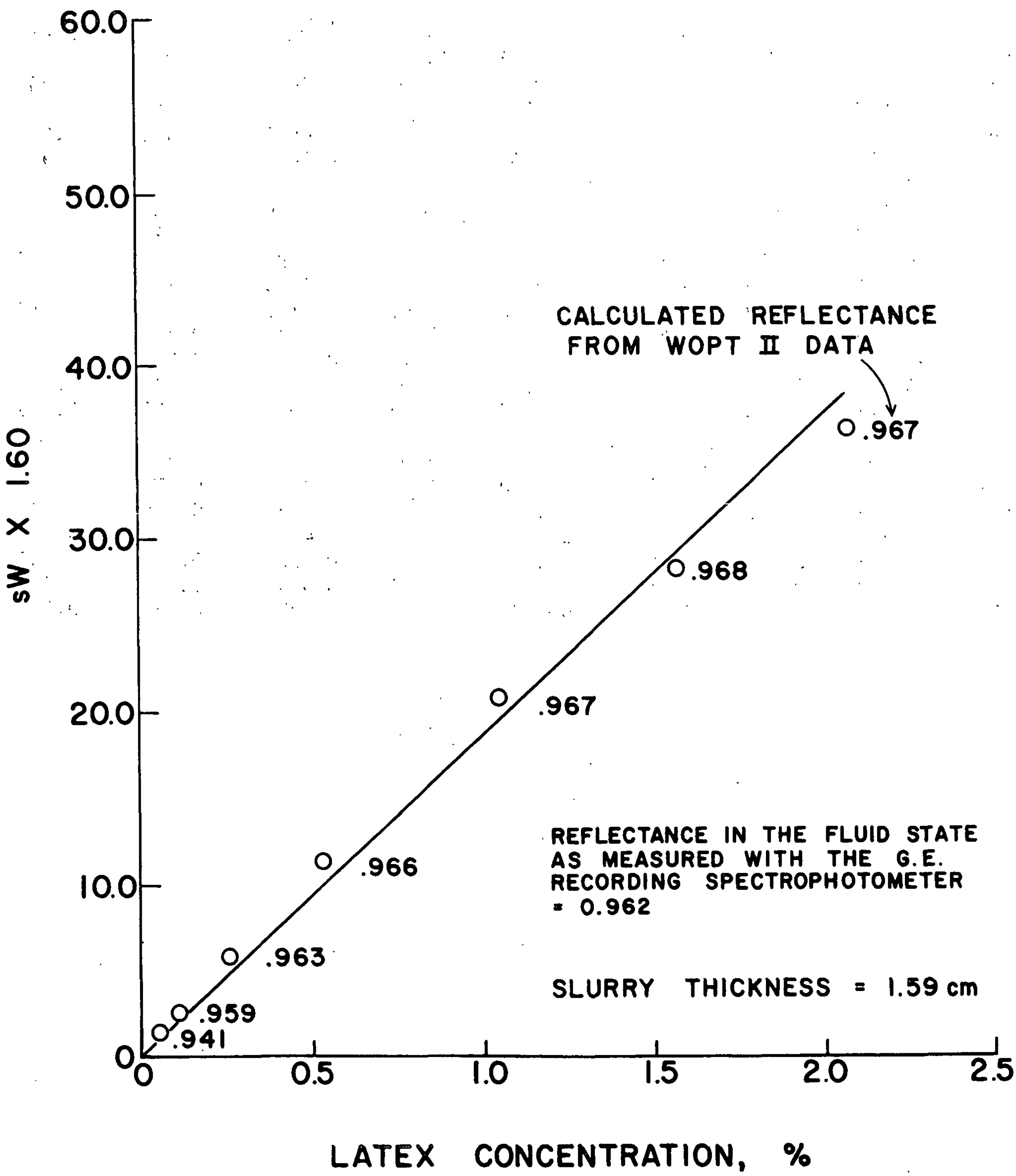

Figure 13. Dependence of Scattering Power on GENFLO 559 Rubber Latex Concentration in Water With the Rigid, Rectangular Plastic Pipe Between the Cavities

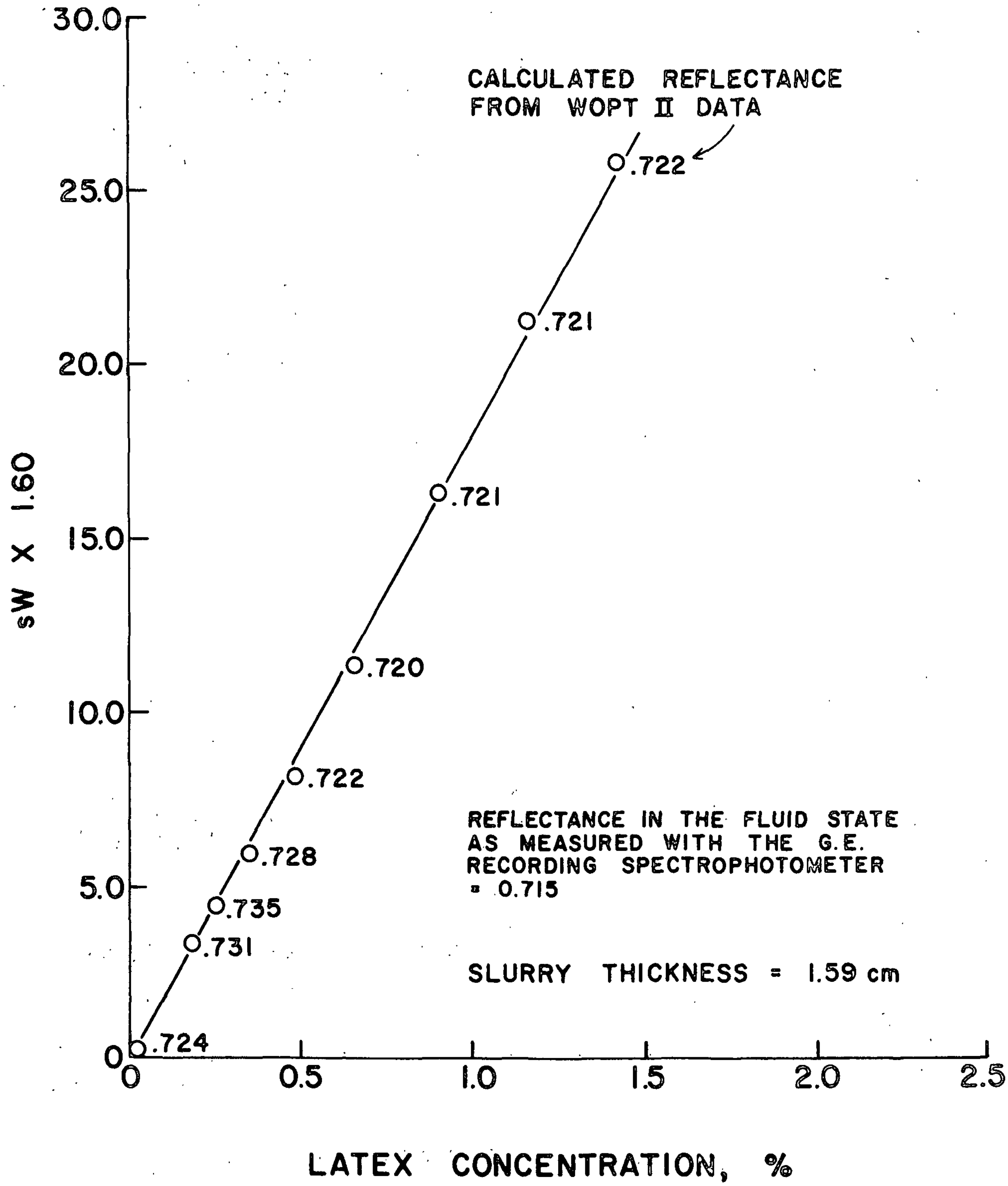

Figure 14. Dependence of Scattering Power on GENFLO 559 Rubber Latex Concentration With Black Dye Added and With the Rigid, Rectangular Plastic Pipe Between the Cavities

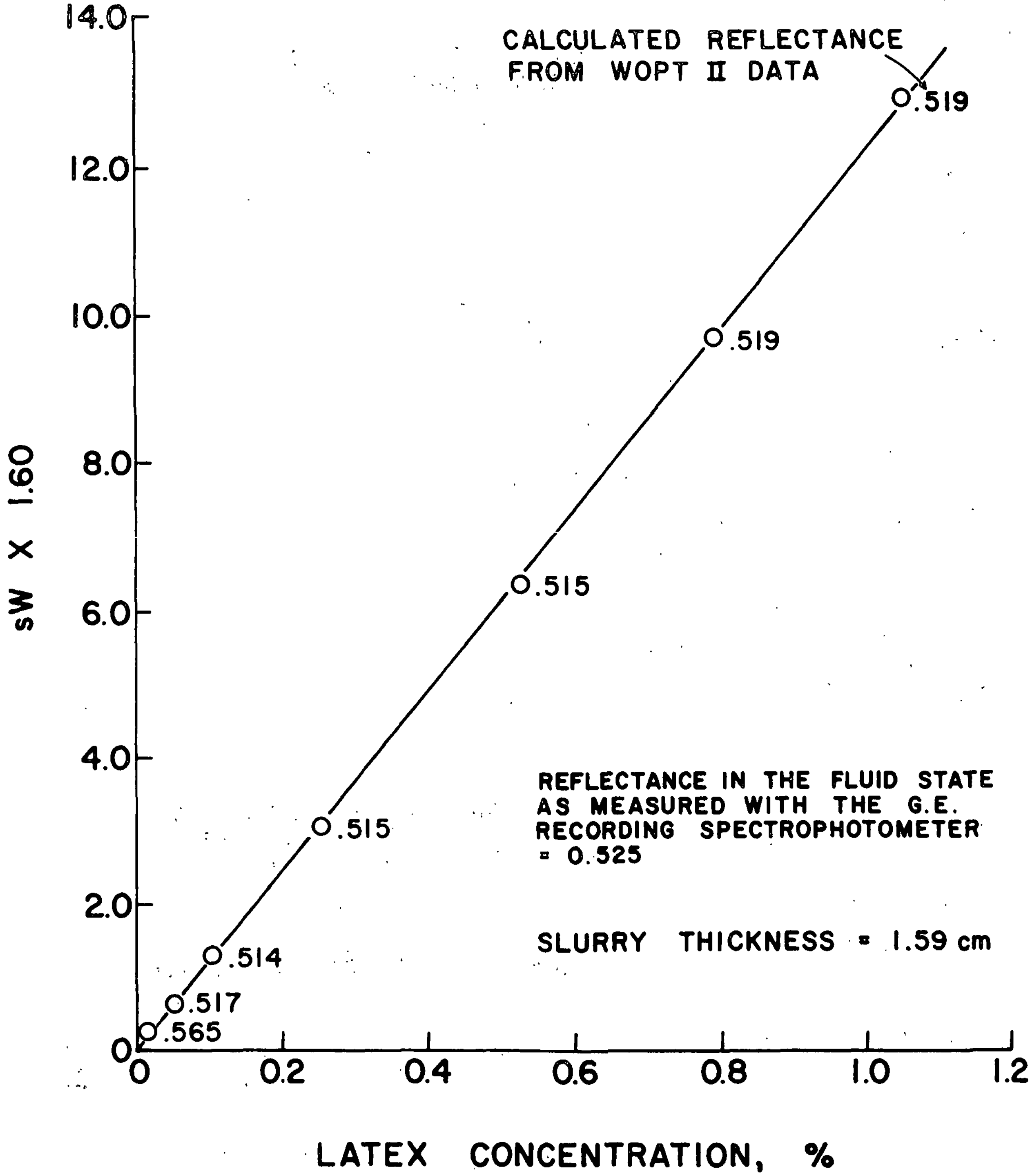

Figure 15. Dependence of Scattering Power on GENFLO 559 Rubber Latex Concentration With Black Dye Added and With the Rigid, Rectangular Plastic Pipe Between the Cavities

TABLE VIII

OPTICAL AND CONSISTENCY DATA FOR FIVE PULPS (WOPT II)

R_o	T	sW	kW	R_∞ wet	R_∞ dry	Standard Brightness, %	x 1.6	Consistency, % gravimetric
Bleached Jack Pine								
0.5318	0.3553	1.410	0.1233	0.660	0.871	0.873	2.26	2.45
0.4985	0.4137	1.161	0.0935	0.671	0.876	0.873	1.86	2.05
0.4389	0.4937	0.870	0.0705	0.670	0.875	0.873	1.39	1.55
0.3320	0.6252	0.527	0.0439	0.667	0.873	0.873	0.84	0.89
0.2168	0.7550	0.286	0.0286	0.642	0.862	0.873	0.46	0.48
Mitscherlich Pulp, Spruce								
0.4929	0.2228	1.759	0.3702	0.528	0.807	0.789	2.81	1.98
0.4100	0.4223	0.912	0.1888	0.531	0.808	0.789	1.46	1.02
0.3018	0.6081	0.488	0.0952	0.541	0.813	0.789	0.78	0.52
0.1852	0.7749	0.238	0.0408	0.561	0.824	0.789	0.38	0.26
Brown Stock, Spruce								
0.1545	0.0361	1.045	2.414	0.155	0.497	0.488	1.67	1.96
0.1542	0.0757	0.813	1.870	0.155	0.498	0.488	1.30	1.49
0.1556	0.1671	0.580	1.277	0.160	0.505	0.488	0.93	1.01
0.1516	0.3778	0.347	0.6607	0.178	0.529	0.488	0.56	0.52
0.1184	0.6255	0.183	0.2986	0.198	0.554	0.488	0.29	0.26
Mixed Hardwood								
0.4593	0.2144	1.648	0.4423	0.488	0.785	0.8 9	2.64	2.47
0.4361	0.2749	1.326	0.3686	0.482	0.781	0.809	2.12	2.00
0.4020	0.3581	1.008	0.2874	0.478	0.779	0.809	1.61	1.52
0.3504	0.4765	0.699	0.1944	0.482	0.781	0.809	1.12	1.02
0.2554	0.6401	0.392	0.1112	0.479	0.780	0.809	0.63	0.52
0.1596	0.7880	0.202	0.0540	0.489	0.785	0.809	0.32	0.26
Bleached Hardwood								
0.5586	0.2567	1.889	0.2181	0.621	0.853	0.878	3.02	2.70
0.5440	0.2867	1.693	0.1956	0.621	0.853	0.878	2.71	2.42
0.5141	0.3495	1.369	0.1516	0.627	0.856	0.878	2.19	1.97
0.4665	0.4334	1.036	0.1074	0.637	0.860	0.878	1.66	1.50
0.3964	0.5373	0.725	0.0692	0.648	0.865	0.878	1.16	1.02
0.2789	0.6694	0.414	0.0533	0.605	0.845	0.878	0.66	0.52
0.1666	0.8037	0.207	0.0301	0.587	0.836	0.878	0.33	0.26

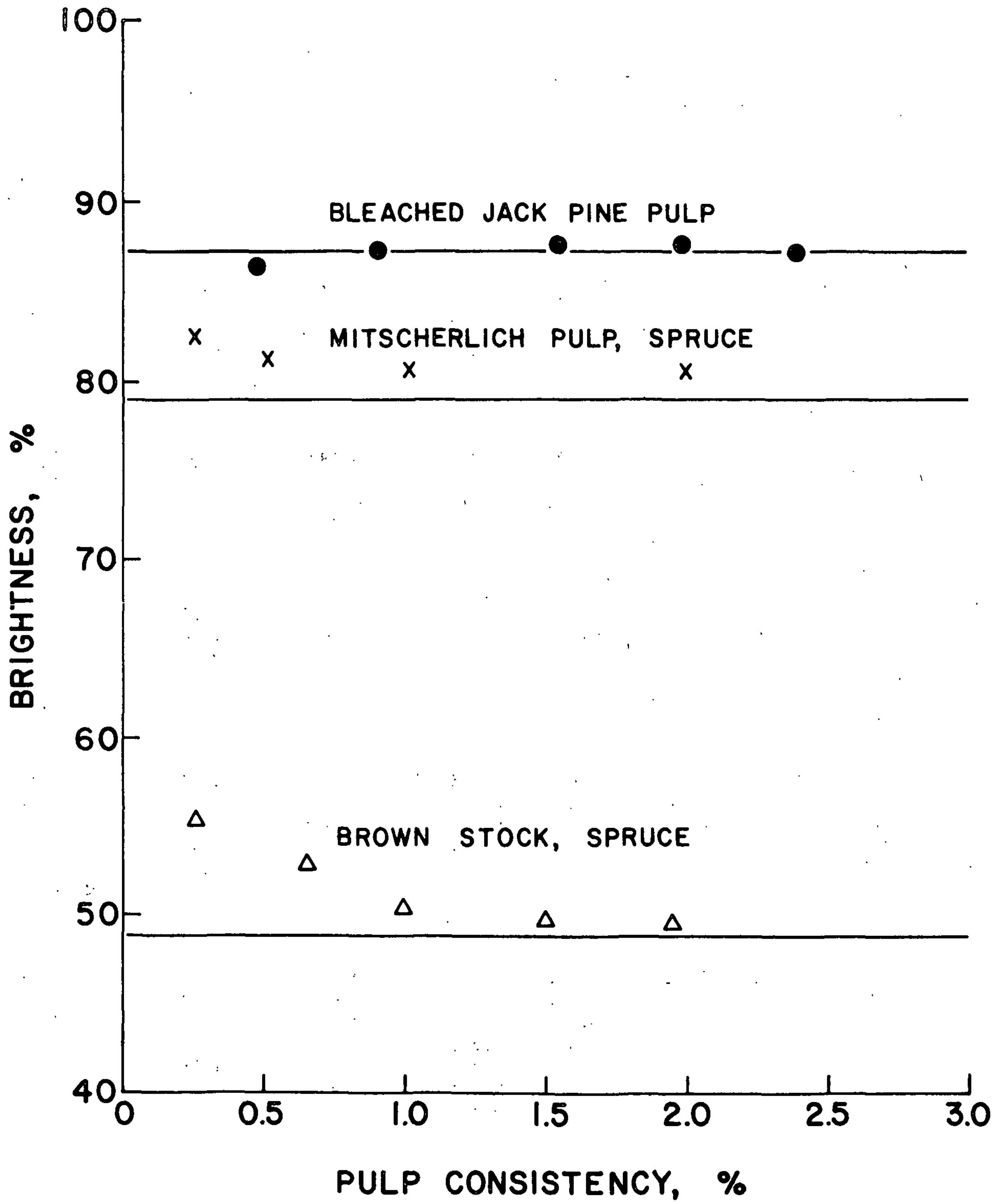

Figure 16. Relationship Between Standard Brightness and Pulp Consistency for Three Different Types of Pulp With the Rigid, Rectangular Plastic Pipe Between the Cavities

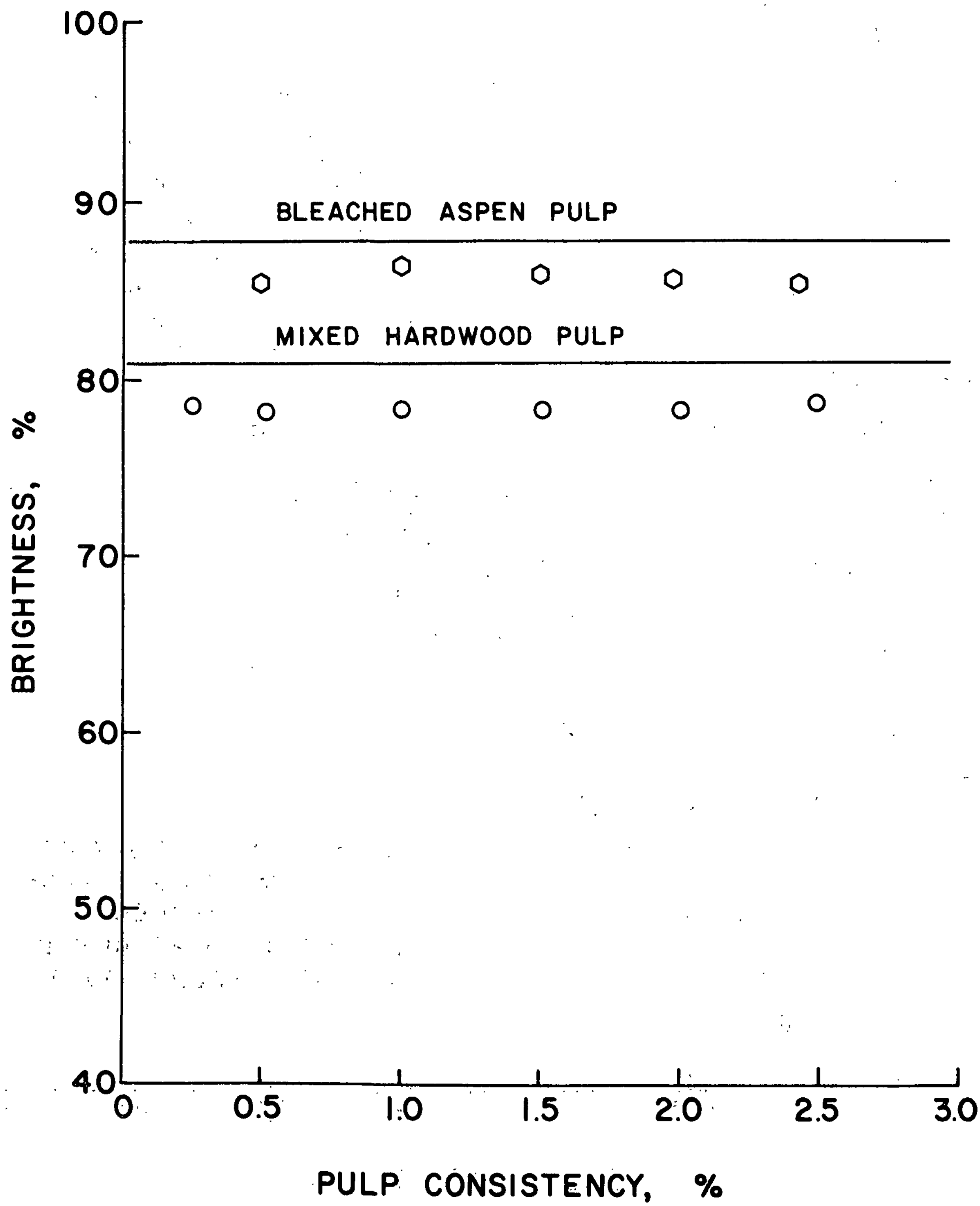

Figure 17. Relationship Between Standard Brightness and Pulp Consistency for Two Different Types of Pulp and With the Rigid, Rectangular Plastic Pipe Between the Cavities

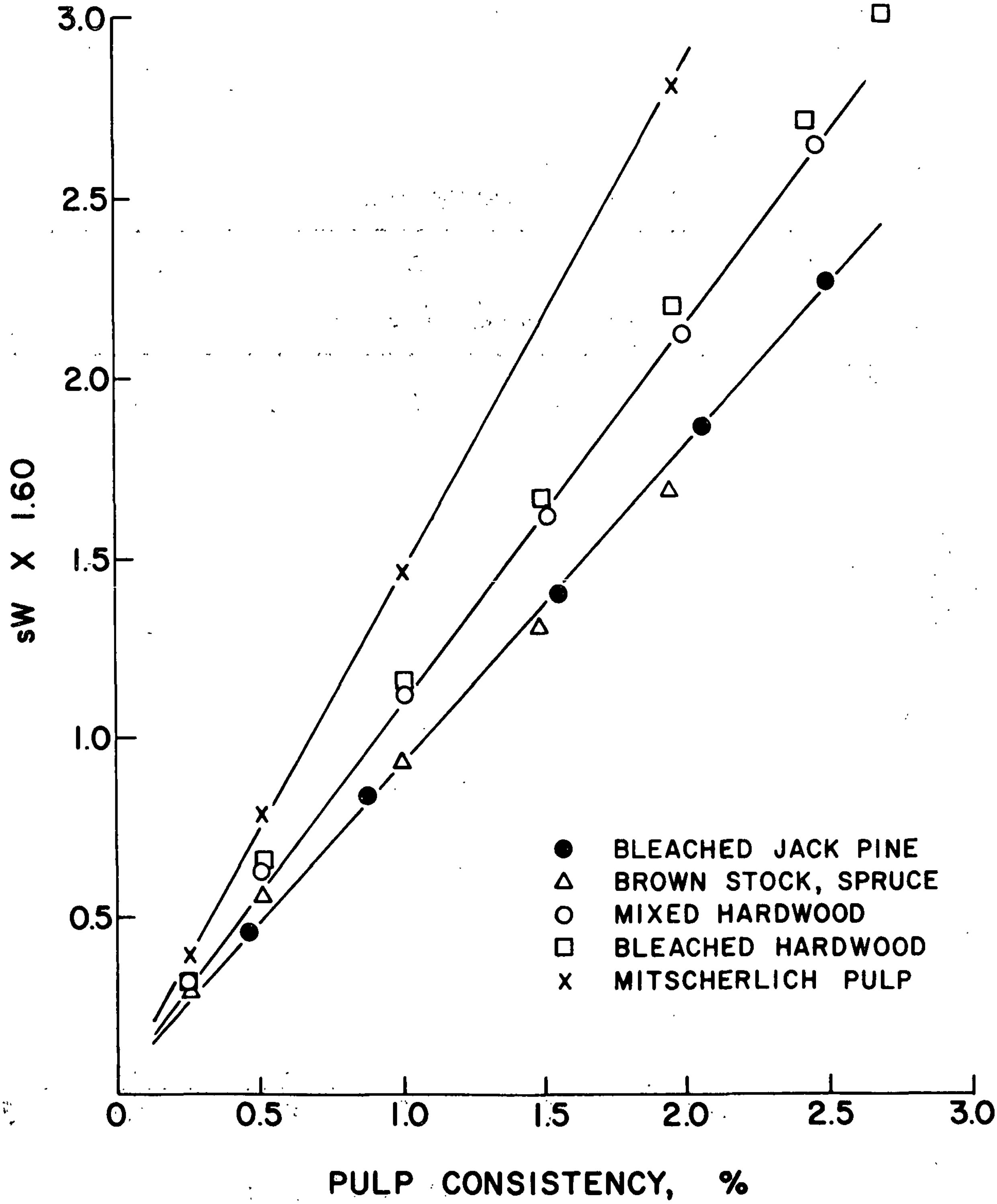

Figure 18. Dependence of Scattering Power on Pulp Consistency for Five Different Types of Pulp With the Rigid, Rectangular Pipe Between the Cavities

SPECTRAL ANALYSIS OF COLORED WATER

Filtrate samples from the chlorination and first dioxide stages for both hardwood and pine furnishes, making a total of four samples, were furnished by Union Camp Corporation, Franklin, VA for spectral analysis. If the colored water has some characteristic absorption peak, it might be possible to use that information to separate the effects of the colored water from the measurements. Four spectral transmittance curves covering the spectral range from 230 to 1050 nm were obtained with the Beckman DK-2A Spectrophotometer. These are shown in Fig. 19 and 20. The curves from 350 to 1050 nm were obtained at the original concentration using a one-cm thick cell. The same one-cm thick cell was used for the ultraviolet, but the sample was diluted with water so that a reasonable transmittance value would be obtained. No absorption peaks were observed. An alternate approach to the colored water problem would be to sample the colored water and evaluate it separately. If information for the colored water and for the colored water plus pulp could be obtained, it should be possible to characterize the pulp.

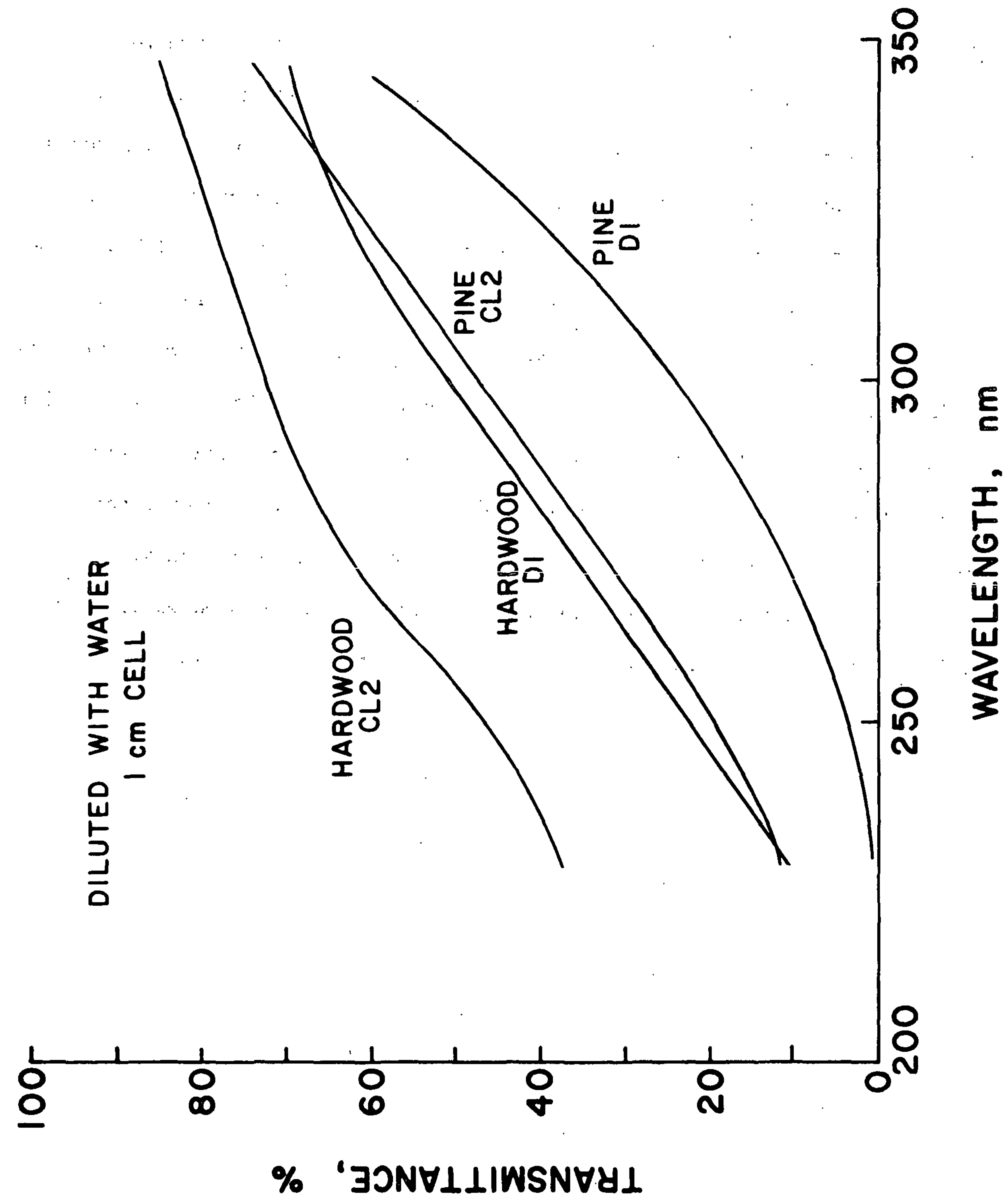

Figure 19. Spectral Transmittance Curves for Four Samples of "C and D-1 Stage Filtrate" (Diluted With Water) Furnished by Union Camp Corporation, Franklin, VA.

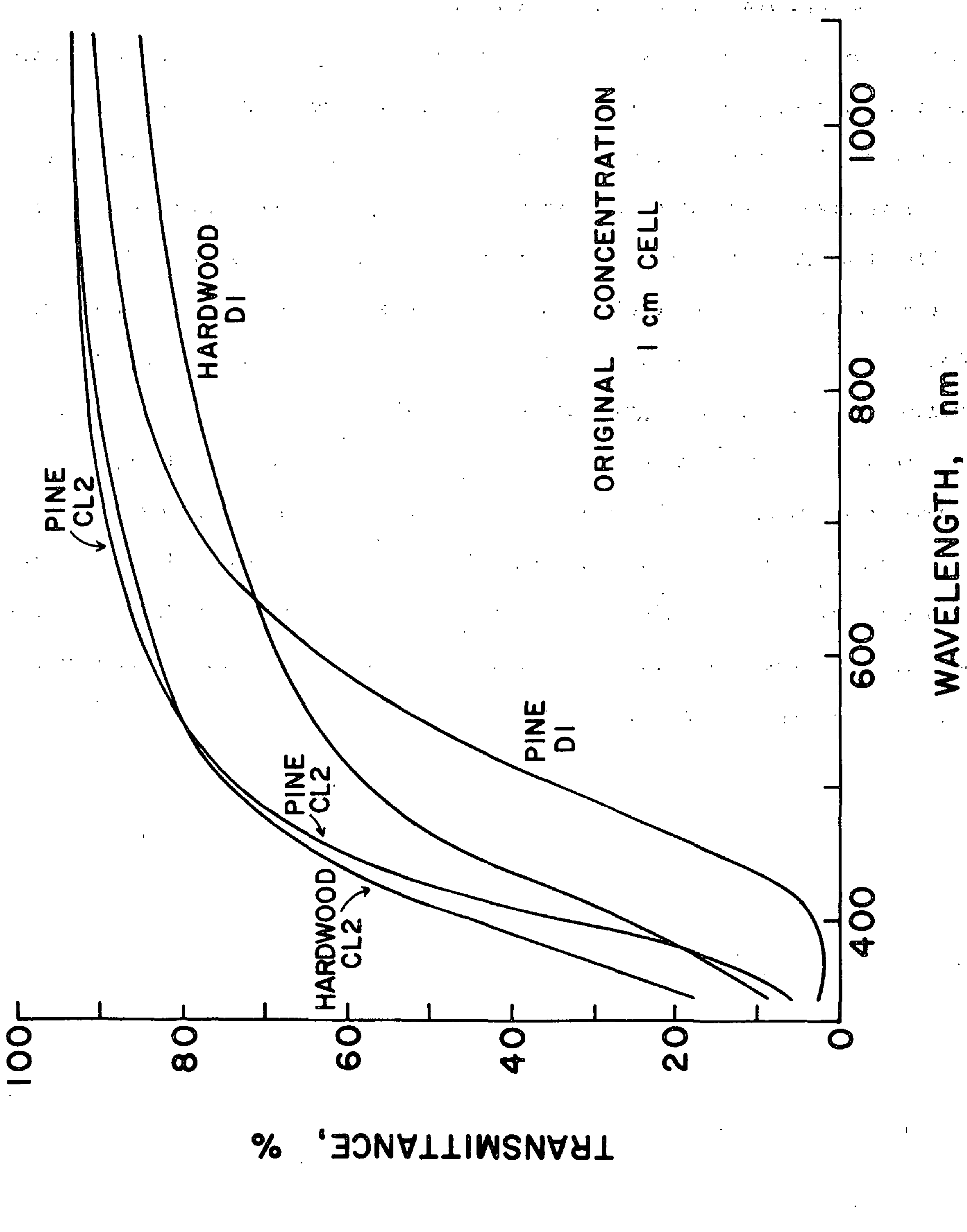

Figure 20. Spectral Transmittance Curves for Four Samples of "C and D-1 Stage Filtrate" (Undiluted) Furnished by Union Camp Corporation, Franklin, VA.

CONCLUSIONS

All data indicate that the relationship between pulp brightness and consistency as determined in slurry form agrees quite well with the data obtained in the conventional manner. Differences observed between hardwood and softwood are rather small, but the differences for the Mitscherlich pulp are relatively large. This means that the species as well as the process must be considered in the calibration of the instrument for the measurement of consistency. These differences also affect the prediction of brightness. It appears that a second wavelength, probably in the spectral region of 700 nm, could be helpful in several ways. The absorbing power of cellulose is quite low in this spectral region and is relatively independent of the degree of bleaching. Readings at this wavelength would still be influenced by changes in scattering power and could be used in conjunction with the short wavelength readings to determine the influence of small particles on scattering power. Adjustments could thus be made to both the brightness and consistency calculations, giving improved accuracy for a wider range of species and processing.

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APPENDIX I

SYMBOLS AND THEIR DEFINITIONS

R_o Absolute reflectance of the wet handsheet or slurry with a black backing having zero reflectance.

R' Absolute reflectance of the white body backing.

R_R' Absolute reflectance of the wet handsheet with the white body backing.

R_∞ Absolute reflectance equivalent to the absolute reflectance of an infinitely thick handsheet or slurry, wet or dry.

k Specific absorption coefficient, wet or dry.

kW Absorbing power, wet or dry.

s Specific scattering coefficient, wet or dry.

sW Scattering power, wet or dry.

T Hemispherical transmittance of a handsheet or slurry.

APPENDIX II

CALCULATION OF THE FINAL OPTICAL DATA FROM DATA COLLECTED WITH WOPT II

DATA

T_c = Transmittance scale reading with shutter in calibrate mode.

R_{TC} = Reflectance scale reading with shutter in calibrate mode.

T_1 = Transmittance scale reading with shutter set to illuminate the slurry.

R = Reflectance scale reading with shutter set to illuminate the slurry.

R_c = Reflectance scale reading with the calibration paddle in the beam.

T_{RC} = Transmittance scale reading with the calibration paddle in the beam.

R_7 = Reflectance scale reading with calibration paddle in the beam and with the highest reflectance material in the slurry chamber.

T_6 = Reflectance scale reading with shutter in the calibrate mode and with the highest reflectance material in the slurry chamber.

EMPIRICAL FACTORS

F_R = Factor to correct reflectance for edge effects, inter-cavity effects, single-beam errors and collimated beam effects, etc.

F_T = Factor to correct transmittance for the same effects given for F_R.

x = Exponent to establish the correct relationship between high and low reflectance values.

y = Exponent to establish the correct relationship between high and low transmittance values.

Formulas for calculating the "true" R_o and T values:

$$R_o = (R-((T_{RC}\ T_1\ F_R)^x))R_7/R_c$$

$$T = (T_1-((R_{TC}\ T_1\ F_T)^y))T_6/T_c$$

AN EXAMPLE TO SHOW THE ORDER OF MAGNITUDE OF THE CORRECTIONS.

Typical values obtained directly from WOPT II and the empirical factors.

$R = 0.375$

$T_{RC} = 0.114$

$T_1 = 0.346$

$F_R = 1.83$

$x = 1.10$

$R_c = 1.084$

$R_{TC} = 0.03$

$F_T = 6.0$

$y = 3.0$

$$R_o = 0.375 - (0.114 \times 0.346 \times 1.83)^{1.1} \times 1.315/1.084$$
$$R_o = (0.375 - 0.0555)\ (1.315/1.084) = 0.3876$$

$$T = 0.346 - (0.03 \times 0.346 \times 6.0)^{3.0} \times 0.580/0.452$$
$$T = (0.346 - 0.0002)\ (0.580/0.452) = 0.4437$$

The magnitude of the correction depends largely on the transmittance value. As transmittance goes to zero, the correction also goes to zero. The data for the example were for the latex slurry and corresponds approximately to a dry pulp reflectance of 80% and at a pulp consistency of about 1.3%.

Formulas for calculating sW, kW, R_∞ wet, R_∞ dry, and consistency:

$$a = \frac{1 + R_o^{\,2} - T^2}{2R_o}$$

$$b = \sqrt{(a^2 - 1)}$$

$$sW = (1/b)\ \ln\left[(b/T) + \sqrt{(b/T)^2 + 1}\right] - (1/b)\ \ln\left[b + \sqrt{b^2 + 1}\right]$$

$$kW = sW(a-1)$$

R_∞ wet $= a - \sqrt{a^2 - 1}$

k/s wet $= \dfrac{(1 - R)^2}{2\ R}$

k/s dry = 0.11 k/s wet

R_∞ dry = 1 + (k/s dry) $-$ $\sqrt{(k/s\ dry)^2 + (2\ k/s\ dry)}$

Consistency = 1.6 sW (See footnote on Table VI).